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Balancing Effect of a
Two-Phase Induction Motor

Electrical Engineering

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BALANCING EFFECT
OF
A TWO-PHASE INDUCTION MOTOR

BY

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WARD ELMO HALL

THESIS
FOR THE
DEGREE OF BACHELOR OF SCIENCE
IN
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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

GORDON WILLIAM CROSSETT and WARD ELMO HALL

ENTITLED BALANCING EFFECT OF A TWO-PHASE INDUCTION MOTOR

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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INTRODUCTION.

Polyphase systems of distribution are used to a great extent in transmitting power to motors of medium and large sizes; i.e. above ten horse power. These motors may be in the form of synchronous motors, synchronous converters or induction motors. Under certain conditions the polyphase induction motor has a balancing effect upon the circuits, the investigation of which is the subject of this thesis.

GENERAL THEORY.

A polyphase system which supplies power for uses other than driving polyphase motors, will in many instances be found unbalanced; i.e. the pressures across the various phases at any point in the circuit will not be equal. This unbalance is due to a greater load upon one phase than upon another. An example of this kind is a lighting load or a single phase motor load which is not equally distributed to the different phases. The phase which has the greatest load placed upon it will have the greatest resistance and reactance drop. The amount of un-

balance will be greatest at points nearest to the unbalancing load. It is immaterial whether the unequal amounts of drop in pressure in the different phases is due to unequal amounts of current flowing in phases having equal amounts of resistance and reactance, or equal currents flowing in phases having unequal amounts of resistance and reactance. In practice the unbalance condition of the circuit is generally due to both unequal currents and unequal amounts of resistance and reactance in the different phases.

When the phases are unbalanced the transmission losses are increased and, in case of a lighting load, the regulation is very unsatisfactory. It is therefore desirable to keep the phases as near balanced as possible. This may be accomplished more or less completely by the use of some special machine such as a motor-generator set. Under certain conditions it is known that the polyphase induction motor will act in a manner somewhat similar to a motor-generator set, and will tend to balance up the pressures in the different phases. If the polyphase induction motor will produce a balancing effect under ordinary operating conditions it is desirable, from this standpoint, to have such machines in operation upon polyphase circuits.

THEORY OF MOTOR OPERATION.

The polyphase induction motor has two main elements: the stationary portion, known as the stator, and the rotary portion, known as the rotor. Current is generally supplied to the windings upon the stator in which case they are known as the primary windings. The varying field set up by the current in the primary induces a current in the rotor windings which are then known as the secondary windings. There are as many separate circuits in the primary as there are phases for which it is wound. Each phase has as many groups as there are poles. The alternating current in each phase causes the polarity of each group or pole to alternate. Resultant poles are formed by the combined action of the different phases. These resultant poles shift their position with the alternations and form a revolving field. The revolving field produces an electromotive force and current in the secondary windings. The value of this electromotive force and current depends upon the rate at which the magnetic lines of force are cut by the conductors of the secondary. The action of the current in the secondary upon the rotating field of the primary gives a turning torque to the rotor. The current in the secondary decreases as the speed increases up to synchronous speed where no lines of force are cut and the current is zero. When the current in the secondary is zero the torque given to the rotor is also zero. It is evident that the rotor will always revolve at a speed of

a sufficient amount below synchronous speed to produce the torque necessary to equal the opposing torque of the load upon the motor. If mechanical power is applied to the rotor and it is driven above synchronous speed, while a magnetizing current is supplied to the primary, the motor will act as a generator and electrical energy will be given out to the circuit.

DESCRIPTION OF APPARATUS.

In these tests power was supplied to the motor by means of a motor generator set which consisted of a direct current 45 K.W. Westinghouse generator, receiving power from the University power plant and delivering power through a belt drive to a Westinghouse two phase generator having a capacity of 100 amperes and delivering current at a pressure of 440 volts.

The motor upon which the experiments for balancing effect were made was a 15 horse power, 400 volt, two phase induction motor built by the Westinghouse Electric Mfg. Co. This motor is of a type and size which is in very common use upon polyphase distributing circuits. The circuits were comparatively short and of low resistance as might be expected in laboratory practice. To make the conditions as near as possible to those found in actual practice resistance was placed in series with one of the phases and a lamp bank load placed upon this phase.

The current for both the lamp bank and one phase of the motor, passed through the resistance. This resistance consisted of a rheostat constructed of iron strips wound upon a frame in such a manner as to make it non-inductive. An inductive load could be added to this same phase by placing in series with the lamp bank, the primary coil of a current transformer, the secondary coil of which was opencircuited. The pressure upon the lamp bank was reduced from 440 volts to 110 volts by means of a $7\frac{1}{2}$ K.W. Westinghouse transformer.

A 220 volt, 51 Ampere Triumph Motor was belted to the machine under test. By placing a lamp bank load on the Triumph Motor a load of any desired value could be placed upon the induction motor. The instruments used in the experiments made upon the motor were of the portable type. The voltmeters and ammeters were of the Thompson make and the wattmeters of the Weston make. The connections for the instruments are shown on Plate 15.

METHOD OF MAKING THE TEST.

The first problem to be overcome was to obtain a method for unbalancing the two phases. First a large lamp bank load was placed upon phase "A" but this was found to be impracticable as the resistance of the leads was so low that in order to obtain a sufficient amount of unbalance a very large load had to be added, one that was so large that there was danger

of overloading one of the phases of the generator. As has been stated before it was decided to place a variable resistance in one phase, in addition to this a lamp bank load which was fed through a transformer. The resistance of phase "B" was varied but the resistance of the line remained constant throughout the test. Connections were made as shown on page and the motor was started and brought up to speed by starting with a low pressure and gradually bringing it up by regulating the field excitation of the generator. Readings were taken of pressure, current and power in each phase with the motor operating and then the circuit to the motor was broken and readings of pressure were taken across each phase without the motor on the line. With a constant brake load or the machine chine supplied by a belted motor run as a generator, the percent of unbalance was varied by varying the value of the resistance in Phase "A" and readings were taken as above for each variation. This test was repeated and data taken for different loads on the motor. A similar series of tests were made with an inductive load in series with the lamp bank on Phase "A". For this inductance the primary of a current transformer was used, the secondary of which was opencircuited.

DISCUSSION OF DATA AND RESULTS.

The data taken in these tests consisted of the pressure across each phase, the current in each phase and the power supplied by each phase with the motor operating, and, under the same conditions, the pressure across each phase without the motor. This data was taken for various loads upon the motor and for various amounts of unbalancing, due both to inductive and non-inductive loads on phase "A". From this data was calculated the percents of unbalance with and without the motor. The percent of unbalance in each case was taken as the difference between the pressure readings of the two phases, divided by the pressure reading of the phase which had the higher pressure, i.e., $\frac{E_b - E_a}{E_b}$. The power factor for each reading was obtained by dividing the power of each phase by the product of its respective current and pressure, i.e., $PF = \frac{W}{EI}$.

The motor will have a balancing effect only when the percent difference in phase voltages is less with the motor operating than without it. Referring to Plate Number 1 it will be seen that the motor has a balancing effect throughout the whole range of unbalancing,? only when the motor was operating under 35 percent of its full load. When the motor is loaded above 35 percent of its full load it has a balancing effect only for extreme cases of unbalancing. The points upon these curves marked "X" represent the amount of unbalance at which

the wattmeter readings of phase "A" change from positive to negative. A negative wattmeter reading in phase "A" indicates that instead of receiving power from this phase, the motor is generating and giving out power to it. The data indicates that the balancing effect of the motor may be due both to the fact that it takes the greater amount of power from the phase of higher pressure, with consequently a greater inpedance drop, and that it may generate and supply power to the phase of lower pressure.

The curves shown on Plate 2 were constructed from data given on pages 22-25 This data was taken under the same conditions as that represented by the curves on Plate 1 except that an inductive load was added to phase "A". These curves have practically the same form as those shown on Plate 1 except that for small amounts of unbalancing the curves on Plate 1 show a little more balancing effect than those on Plate 2

The curves shown on Plates 3-8 were constructed from data given on pages 16-21. These curves indicate that as the percent of unbalance increases there is a very rapid increase in the power taken by the motor from phase "B" and a corresponding rapid decrease in power taken from phase "A". The curves also show well the points at which the wattmeter readings change from positive to negative as previously referred to.

The curves shown on Plates 9-12 were constructed from data given on pages 22-25. These curves are similar to those shown on Plates 3-8 except that the curves for the two phases overlap for small percentages of unbalance. The reason why phase

"A" should supply more power to the motor than phase "B", under these conditions, and the motor still show a balancing effect of the pressures across the two phases, can be explained from the fact that the power factor was so much lower in phase "B" than in phase "A" that by multiplying it by its corresponding pressure and current, a lower wattmeter reading could be obtained from phase "B" than from phase "A".

The curves shown on Plates 13-18 were obtained from data given on pages 16-21. It is interesting to note that the power factor of phase "A" increases very rapidly with the percent of unbalance, except at the point where the wattmeter readings reverse; here it suddenly drops to zero and rises again. The power factor of phase "A" has a tendency to remain higher than that of phase "B" under all conditions.

The curves shown on Plates 19-22 were constructed from data given on pages 22-25. These curves are similar to those shown on Plates 13-18 except that they show a little lower power factor for phase "B" under the same conditions of motor load.

A set of data was taken with the motor phases reversed, and comparison made to similar data taken before reversing, to determine whether there were any errors due to the construction of the machine. Practically the same results were obtained in both cases.

CHARACTERISTICS OF MOTOR AND CONSTRUCTION OF CIRCLE DIAGRAM.

One of the most interesting points discovered in connection with this thesis is the fact that the machine will operate as a motor generator when running below synchronous speed.

Such operating conditions were obtained as follows. The motor was started in the usual way, that is, as a two phase machine and when up to speed phase A was opened at the generator which was equivalent to inserting an infinite resistance and obtaining a hundred percent unbalance. Upon opening this phase the voltage, instead of dropping from 440 to zero, only dropped about 60 volts and the wattmeter showed a negative reading. Exact data may be found on page 26. It was decided that the machine was operating as a single phase induction motor taking all its power from phase B of the generator and supplying power through a transformer to a lamp bank. From the data just referred to curves were plotted as shown on Plates 23-25. It is seen that the maximum efficiency when operating under these conditions is about 63 percent. The power factor curve shows that with an increase of power cos. θ increases in phase B and in phase A remains constant and equal to one, due to the character of the load on this phase. Plate shows the relation between watts in each phase and pressure. In phase "A" we see that as the power increases the voltage decreases the curve showing the variation taking the form of a straight line.

Besides determining the efficiency of the machine when being run as a motor-generator it was thought best to show some of its characteristic curves when running on balanced phases and under normal conditions. To accomplish this, use was made of the Circle Diagram. By this method accurate results were obtained or results that agree with the manufacturer's rating of the machine. Data for the curves and diagrams was obtained by running the motor light and impressing upon it different values of voltage at normal rated frequency. The voltage was varied from above normal to as low a value as the motor would operate upon; that is, it was varied from 474 to 33 volts. Next the rotor was blocked and different values of voltage at the same frequency were applied sufficient to cause current from zero to 50% overload to flow. Values of current, voltage and watts in each phase were taken and also the resistance of the primary winding.

On Plate 26 are shown curves between voltage, which in each case are used as abscissae, and watts I^2R loss and ampere input. The data for these curves was taken with motor running light, and may be found on page 27. The watt curve was produced until it cut the vertical axis and then at this point a line was drawn parallel to the volt axis. Now the friction loss can be read directly from the curve and is measured in watts, it being the distance to the line parallel to the volt axis. Curves were next plotted using data shown on page 28

which was taken with the rotor blocked, ampere input being used as abscissae and voltage, watta and I^2R loss as ordinates. In drawing the Circle Diagram as shown on Plate 30 the E. M. F. is laid off in a vertical direction and is used as one axis, the other being M A drawn at right angles to it. With O as a center laid off M O the no load current to scale one inch equals ten amperes. This value was taken from the current curve on Plate and for the normal voltage, that is, 400 volts. The current vector was laid off with the proper phase relation to the voltage M.E. O K was drawn parallel to M A and M F was drawn equal to the short circuited (blocked rotor) current at normal voltage and frequency and at the proper phase relation with M E. Through O and F passed a semicircle and with its center in O K. This curve is the locus of the primary current for all values of load on the motor. Took any value of stater current as M P. Angle E M P is the phase angle for this input and P T represents the current in phase with the E M F , and hence may to the proper scale represent the watts input to the motor. The current M T is the wattless current. On M E some distance is chosen as M D which may be easily divided into one hundred equal parts. Using this as a radius and with a center at M an arc of a circle was drawn. Through B the intersection of M P with this arc B C was drawn parallel to M A. Then M C is the power factor at that load. The distance S T or M N represents the no load losses. Let R S be taken equal to the additional I^2R losses in the primary at the load current M P. The straight line ORJ was drawn and also

C F cutting P T at Q. Then Q R is the secondary I^2R loss at this load.

Now $\frac{PR}{QR}$ = slip with synchronism as unity.

$\frac{QP}{PR}$ = speed.

Q P = Output of motor.

$\frac{QP}{PT}$ = efficiency.

P R = torque in synchronous watts.

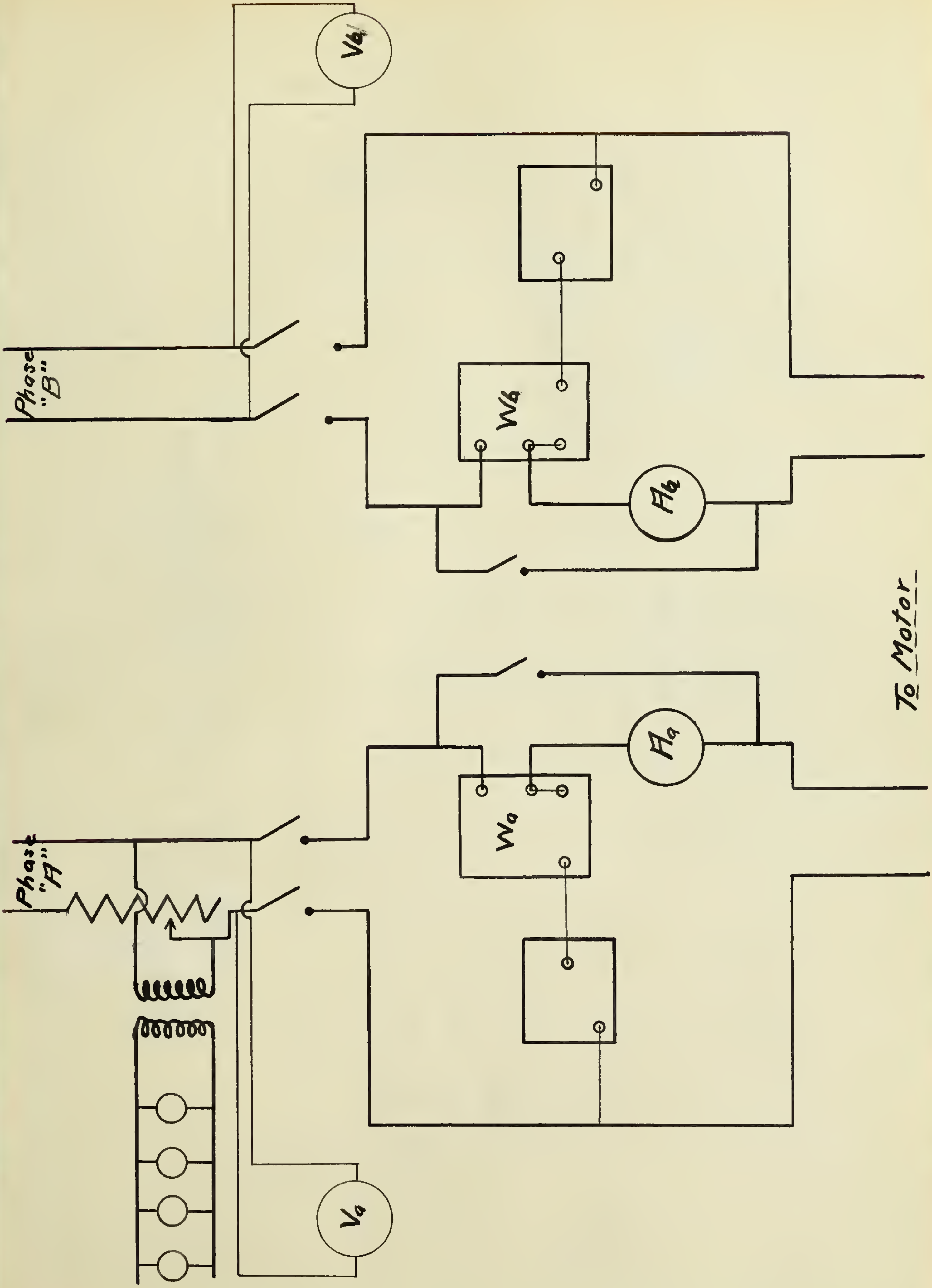
$\frac{PR \times 7.04}{\text{Synchronous speed}}$ = torque in pound feet.

To obtain the efficiency directly from the diagram F O was produced to G and the perpendicular G H was drawn. Produced O F. Then line H L was drawn parallel to M A and at such a distance as to make it easily divisable into one hundred equal parts. Drew G P and extended it to H L cutting at V. L V is then the percent efficiency. To be able to read the slip directly from the diagram O W was drawn perpendicular to O K. W X was drawn parallel to O J and at such a distance as to give a convenient scale of percent, or R P M of the motor at synchronous speed. The intersection of O P produced to cut the line W X at Y gives W Y the percent slip and Y X the full load speed in percent of synchronous speed. Values of speed, power factor, efficiency, torque, and ampere input were taken from the diagram and curves plotted using horse power output as abscissae. These curves are shown on Plate 28.

CONCLUSIONS.

For circuits unbalanced less than twenty percent of the pressure of the phase of higher pressure the two-phase induction motor has a balancing effect upon the phases when operating at loads less than thirty-five percent of rated full load.

The two-phase induction motor may be operated as a motor generator taking power from one phase and supplying power to the other. Under such conditions the efficiency of the machine is low as compared with that of the ordinary form of motor-generator. Where the motor has a balancing effect on the circuit the power factor of the phase of higher pressure is lower than it is under normal conditions and the power factor of the phase of lower pressure is higher. It will be seen that where the motor is advantageous in balancing the pressure of the circuit it also has the disadvantage of unbalancing the power factors in the phases.


Vb
Phase "B"
Wb
Ab
To Motor
Aa
Wa
Phase "A"
Va

NO LOAD ON MOTOR

NON-INDUCTIVE LOAD ON PHASE "A"

W_a	E_a	I_a	$\frac{W_a}{E_a I_a}$ $P.F_a$	W_b	E_b	I_b	$\frac{W_b}{E_b I_b}$ $P.F_b$	E'_a	E'_b	% $\frac{E_b - E_b}{E_b}$	% $\frac{E'_b - E'_a}{E'_b}$
440	434	6.5	.16	480	440	7.4	.15	452	460	1.36	1.74
480	427	5.5	.20	400	440	8.2	.12	445	463	2.95	3.90
480	423	4.9	.23	400	440	8.7	.10	438	464	3.86	5.73
440	412	3.8	.28	480	440	9.7	.11	430	466	635	7.74
160	399	1.4	.29	840	440	11.1	.19	412	466	9.30	11.60
-000	392	1.8	.00	1000	440	11.6	.20	402	466	10.90	1410
-600	373	1.9	.85	1760	440	13.3	.29	357	470	15.20	24.00
-760	372	2.3	.89	2000	440	13.6	.33	345	470	15.40	26.60
-1040	363	3.0	.96	2320	440	14.2	.40	315	469	17.40	27.10
-2240	356	6.2	1.00	3600	440	16.0	.51	0	450	19.10	100.00

33 PER-CENT LOAD ON MOTOR
NON-INDUCTIVE LOAD ON PHASE "A"

W_a	E_a	I_a	$\frac{W_a}{E_a I_a}$ $P.F._a$	W_b	E_b	I_b	$\frac{W_b}{E_b I_b}$ $P.F._b$	E_a'	E_b'	% $\frac{E_b - E_a}{E_b}$	% $\frac{E_b' - E_a'}{E_b'}$
1800	434	7.7	.54	1960	440	8.6	.52	457	465	1.36	1.72
1800	425	6.7	.63	1980	440	9.7	.47	445	463	3.41	3.89
1760	418	6.0	.70	2040	440	10.4	.44	440	465	5.00	5.38
1600	406	5.0	.79	2160	440	11.6	.42	430	465	7.30	7.53
680	377	9.1	.20	3320	440	14.6	.52	397	470	14.30	15.60
000	358	1.6	.00	4000	440	16.6	.55	359	473	18.60	24.10
-50	355	1.8	.78	4560	440	16.8	.62	345	473	19.30	27.00
-640	347	1.9	.95	5160	440	18.4	.64	310	479	21.10	34.90
-2000	337	6.0	.99	6800	440	21.0	.74	000	475	23.40	100.00

49.2 PER-CENT LOAD ON MOTOR

NON-INDUCTIVE LOAD ON PHASE "A"

W_a	E_a	I_a	$\frac{W_a}{E_a I_a}$ PF_a	W_b	E_b	I_b	$\frac{W_b}{E_b I_b}$ $P.F_b$	E_a'	E_b'	% $\frac{E_b - E_a}{E_b}$	% $\frac{E_b' - E_a'}{E_b'}$
2760	435	9.1	.70	2920	440	10.0	.67	455	462	1.13	1.52
2840	422	8.4	.83	3200	440	11.5	.63	447	465	4.10	3.87
2600	414	7.4	.85	3080	440	11.9	.59	443	467	5.91	5.15
2320	401	6.4	.91	3400	440	13.5	.57	430	465	8.87	7.94
1800	380	4.5	1.00	4080	440	15.6	.60	412	465	13.60	11.30
680	352	2.8	.69	5680	440	19.2	.67	369	470	20.00	20.00
000	342	2.3	.00	6160	440	20.5	.68	340	474	22.20	28.50
-1920	327	5.6	1.00	8400	440	25.00	.76	0	477	25.90	100.00

65 PER-CENT LOAD ON MOTOR
NON-INDUCTIVE LOAD ON PHASE "A"

W_a	E_a	I_a	$\frac{W_a}{E_a I_a}$ $P.F._a$	W_b	E_b	I_b	$\frac{W_b}{E_b I_b}$ $P.F._b$	E'_a	E'_b	% $\frac{E_b - E_a}{E_b}$	% $\frac{E'_b - E'_a}{E'_b}$
3640	417	9.9	.88	3920	440	12.8	.70	450	465	5.22	3.23
3240	397	8.4	.97	4240	440	14.8	.65	440	467	9.78	5.30
2820	383	7.6	.99	4720	440	16.5	.65	427	467	12.95	8.58
2620	375	7.0	1.00	5200	440	17.5	.67	425	467	14.75	9.00
2200	364	6.1	.99	5680	440	19.0	.68	413	467	17.26	11.56
1700	353	5.1	.96	6280	440	20.5	.70	397	467	19.76	15.00
1140	340	4.1	.83	7040	440	22.6	.71	370	470	22.72	21.30
580	330	3.2	.55	7800	440	24.0	74	357	472	25.00	24.40

82 PER-CENT LOAD ON MOTOR
NON-INDUCTIVE LOAD ON PHASE "A"

W_a	E_a	I_a	$\frac{W_a}{E_a I_a}$ $P.F_a$	W_b	E_b	I_b	$\frac{W_b}{E_b I_b}$ $P.F_b$	E_a'	E_b'	% $\frac{E_b-E_a}{E_b}$	% $\frac{E_b'-E_a'}{E_b'}$
4720	432	13.4	.82	4720	440	13.3	.81	458	464	1.82	1.29
4760	418	12.6	.90	5080	440	14.8	.78	452	465	5.00	2.80
4360	400	11.3	.97	5280	440	16.4	.73	443	465	9.10	4.73
4000	383	10.4	1.00	5760	440	18.2	.72	435	466	12.95	6.65
3640	372	9.4	1.00	6120	440	19.5	.71	430	468	15.45	8.10
3320	364	8.9	1.00	6440	440	20.6	.71	423	468	17.25	9.60
2260	337	6.9	.97	7520	440	24.6	.70	400	470	23.40	14.90

FULL LOAD ON MOTOR
NON-INDUCTIVE LOAD ON PHASE "A"

W_a	E_a	I_a	$\frac{W_a}{E_a I_a}$ P.F.$_a$	W_b	E_b	I_b	$\frac{W_b}{E_b I_b}$	E_a'	E_b'	% $\frac{E_b - E_a}{E_b}$	% $\frac{E_b' - E_a'}{E_b'}$
5960	430	15.5	.90	5880	440	15.7	.85	457	465	2.27	1.72
5520	407	14.0	.97	6160	440	17.8	.82	446	463	7.50	3.68
4760	388	12.0	1.00	6200	440	19.2	.74	435	464	11.80	6.25
4400	352	11.4	1.00	7600	440	23.8	.73	425	465	20.00	8.60
3840	347	10.5	1.00	8520	440	26.0	.74	415	467	21.00	11.00

NO LOAD ON MOTOR
INDUCTIVE LOAD ON PHASE "A"

W_a	E_a	I_a	$\frac{W_a}{E_a I_a}$ P.F.a	W_b	E_b	I_b	$\frac{W_b}{E_b I_b}$ P.F.b	E'_a	E'_b	% $\frac{E_b - E_a}{E_b}$	% $\frac{E'_b - E'_a}{E'_b}$
520	437	6.4	.18	32	440	7.4	.01	457	464	0.7	1.5
640	418	4.5	.34	24	440	9.0	.006	440	465	5.0	3.2
480	405	2.7	.44	560	440	10.8	.12	421	467	8.0	9.7
20	390	1.5	.03	800	440	11.9	.15	404	468	11.0	13.7
-24	376	1.1	.06	1360	440	13.1	.23	371	473	14.0	21.6
-560	369	1.8	.84	1760	440	13.8	.29	340	472	16.0	28.0
-1640	358	4.7	.97	3040	440	15.0	.46	000	477	18.5	100.00

33 PER-CENT LOAD ON MOTOR
INDUCTIVE LOAD ON PHASE "A"

W_a	E_a	I_a	$\frac{W_a}{E_a I_a}$ P.F.$_a$	W_b	E_b	I_b	$\frac{W_b}{E_b I_b}$ P.F.$_b$	E'_a	E'_b	% $\frac{E_b - E_a}{E_b}$	% $\frac{E'_b - E'_a}{E'_b}$
1960	433	7.7	.59	1880	440	8.5	.50	457	463	1.6	1.3
1920	422	6.7	.68	1840	440	9.6	.44	449	465	4.1	3.4
1760	406	5.1	.85	2000	440	11.6	.39	435	467	7.7	6.9
600	372	1.9	.85	3200	440	14.5	.50	393	473	15.4	16.9
000	358	1.6	.00	4000	440	16.5	.55	359	475	18.5	24.4

65 PER-CENT LOAD ON MOTOR
INDUCTIVE LOAD ON PHASE "A"

W_a	E_a	I_a	$\frac{W_a}{E_a I_a}$ P.F.$_a$	W_b	E_b	I_b	$\frac{W_b}{E_b I_b}$ P.F.$_b$	E'_a	E'_b	% $\frac{E_b-E_a}{E_b}$	% $\frac{E'_b-E'_a}{E'_b}$
3840	432	10.8	.82	3600	440	10.4	.79	455	460	1.8	1.1
3760	416	9.8	.93	3680	440	12.7	.66	447	463	5.5	3.5
2760	387	7.7	.93	4320	440	16.0	.61	427	465	12.0	8.2
1880	357	5.5	.96	5760	440	19.7	.67	404	469	18.8	13.8
880	334	3.7	.71	7200	440	23.5	.70	368	475	24.2	22.8
520	328	3.2	.50	7920	440	24.7	.73	349	470	25.5	25.5

FULL LOAD ON MOTOR
INDUCTIVE LOAD ON PHASE "A"

W_a	E_a	I_a	$\frac{W_a}{E_a I_a}$ P.F.$_a$	W_b	E_b	I_b	$\frac{W_b}{E_b I_b}$ P.F.$_b$	E'_a	E'_b	% $\frac{E_b - E_a}{E_b}$	% $\frac{E'_b - E'_a}{E'_b}$
6000	430	15.6	.90	5880	440	15.8	.85	453	460	2.3	1.5
5800	408	14.6	.97	6320	440	18.0	.80	446	462	7.3	3.5
5720	382	13.4	1.00	6800	440	20.6	.75	433	462	13.0	6.3
3840	348	11.0	1.00	8280	440	25.5	.74	417	469	21.0	11.1

MOTOR-GENERATOR ACTION

NON-INDUCTIVE LOAD ON PHASE "A"

E_a	I_a	W_a	$\frac{W_a}{E_a I_a}$ P. F.	E_b	I_b	W_b	$\frac{W_b}{E_b I_b}$ P. F.	$E_b - E_a$	$\frac{W_a}{W_b}$ Eff.	E'_a	E'_b
373	1.20	464	1,00	440	12.8	1680	,30	67	,276	00	468
371	2.10	800	1,00	440	13.0	2040	.36	69	.392	00	468
368	2.90	1080	1.00	440	13.8	2320	.38	72	.466	00	468
365	3,73	1388	1.00	440	14.2	2600	,40	75	,534	00	468
358	5.27	1920	1.00	440	15.0	3400	,51	82	,565	00	468
353	6,52	2348	1,00	440	16.0	3800	,54	87	,618	00	468
348	7.83	2780	1,00	440	17.0	4400	,59	92	,632	00	468
340	9.07	3140	1,00	440	18.0	5000	,63	100	,628	00	468

EFFICIENCY TEST
MOTOR RUNNING LIGHT

E_a	I_a	$K.W_a$	E_b	I_b	$K.W_b$	I^2R	Total K.W.
472	7.7	.920	488	8.0	.960	87.9	1880
424	7.0	.800	442	7.2	.840	72.7	1640
368	6.1	.680	386	6.3	.700	61.9	1380
322	5.2	.560	337	5.5	.590	40.9	1150
280	4.3	460	374	4.4	.485	34.1	945
232	4.0	440	240	4.1	.415	23.5	855
185	3.2	360	194	3.3	.355	15.0	715
140	3.2	300	146	3.1	.305	14.1	605
110	3.2	260	116	3.2	.270	14.3	550
83.5	3.0	240	82	36	.235	18.8	475
49	4.3	160	46.3	4.8	.210	29.9	370
33	4.1	08	28	38	.195	21.8	228
				$R = .715$			

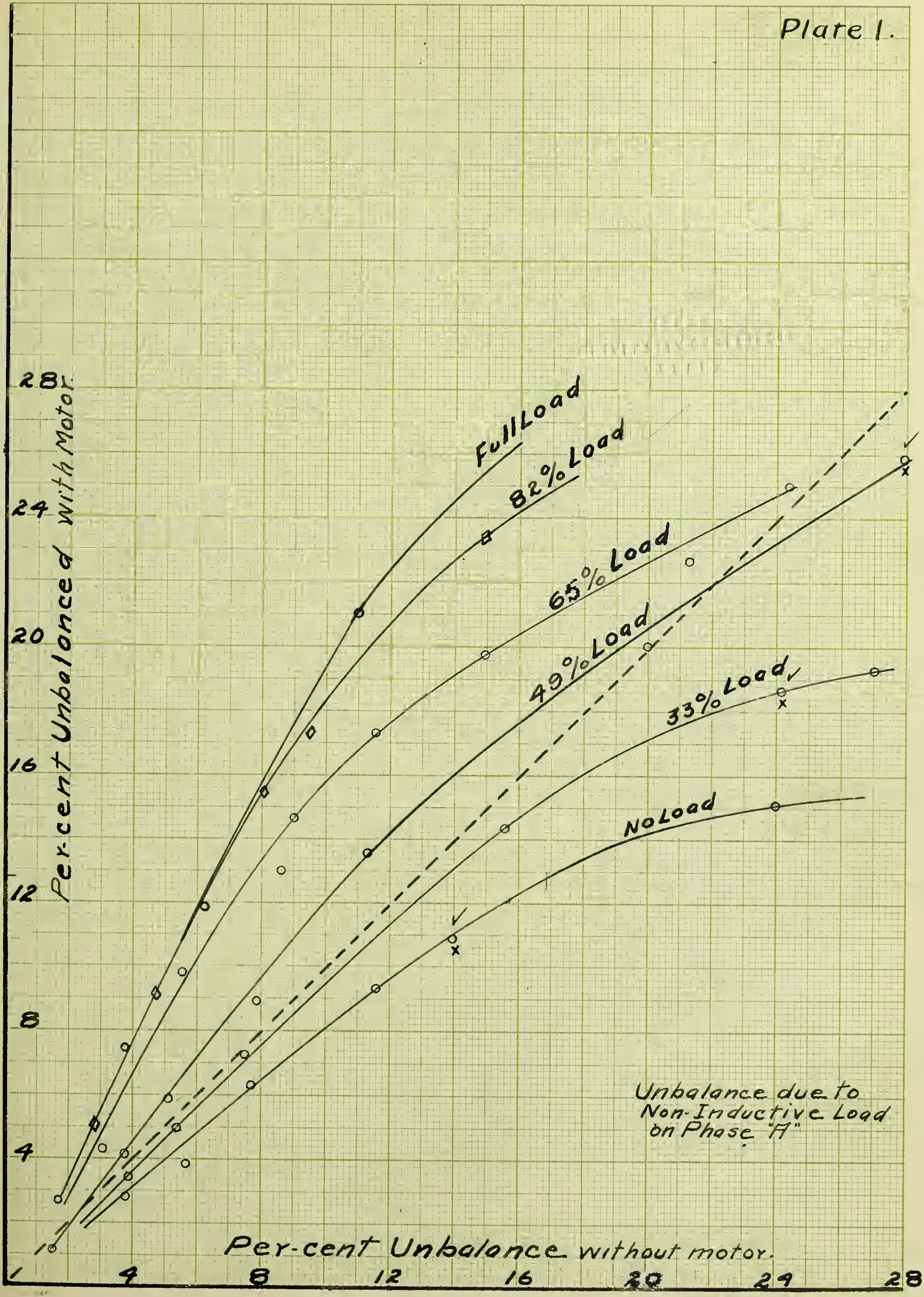
EFFICIENCY TEST
ROTOR BLOCKED

E_a	I_a	K.W.a	E_b	I_b	K.W.b	I^2R	Total K.W.
25.0	5.2	.032	23.5	4.7	.060	35	.092
42.5	9.1	.210	41.5	9.0	.195	117	.405
59.0	12.9	.420	57.0	12.7	.380	232	.800
72.0	15.7	.620	70.0	15.4	.570	345	1.190
87.0	19.0	.989	85.0	18.6	.840	504	1.829
97.0	21.0	1.100	95.0	20.6	1.500	618	2.600
111.0	24.2	1.420	109.0	23.7	1.380	813	2.800
116.0	25.4	1.600	111.5	25.0	1.560	907	3.160

EFFICIENCY TEST
VALUES FROM DIAGRAM

H.P. Out Put	R.P.M	Torque in lb. feet	Per-Cent. Eff.	P.F.	Current In Put.
0	1120	00.0	00.0	.290	13.0
5	1092	21.8	72.5	.740	18.8
10	1067	45.8	79.5	.833	28.8
15	1036	71.0	81.0	.900	39.5
20	947	98.0	78.0	.903	54.4

Plate I.



Unbalance due to
Non-Inductive Load
on Phase "A"

Plate 2

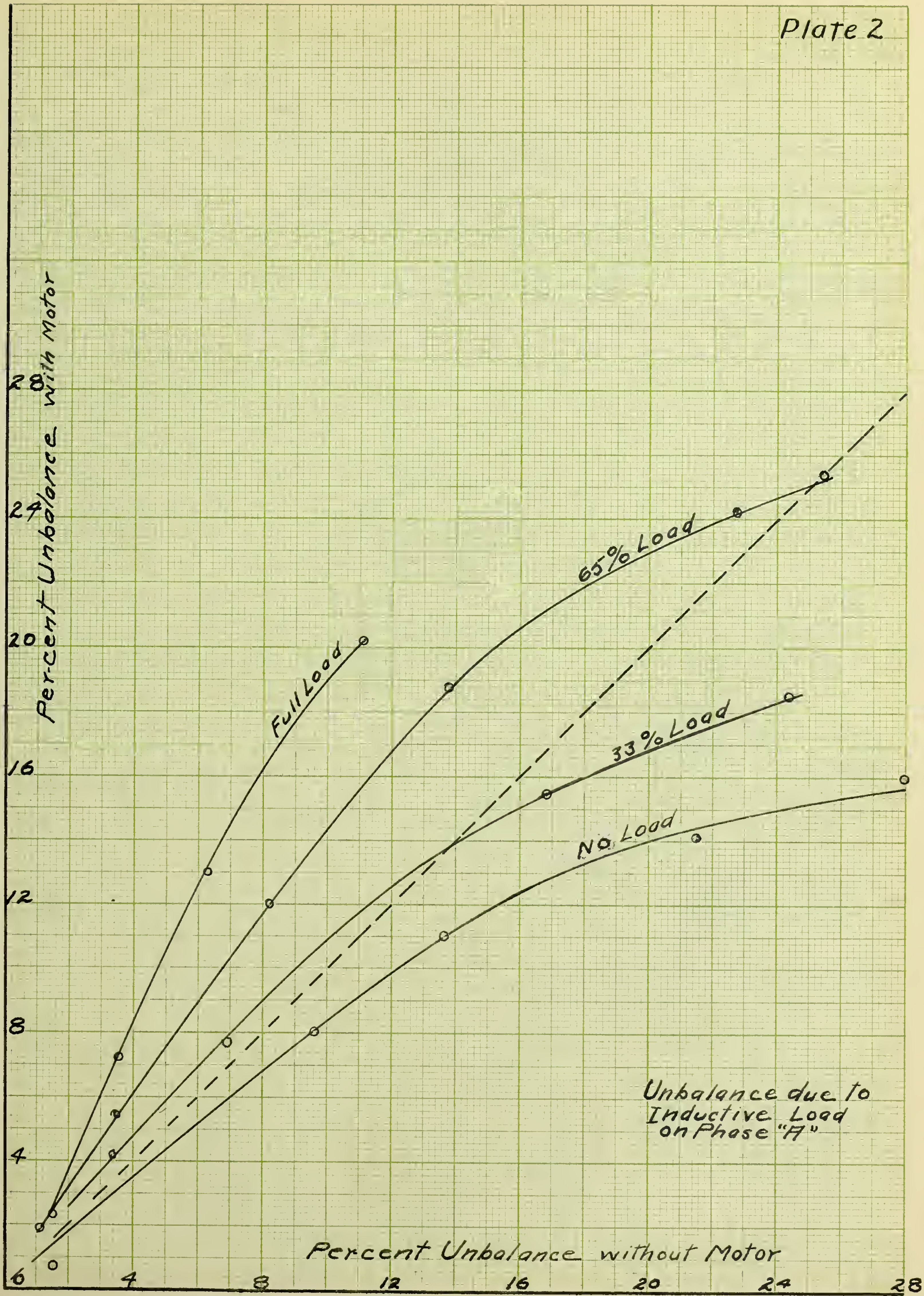
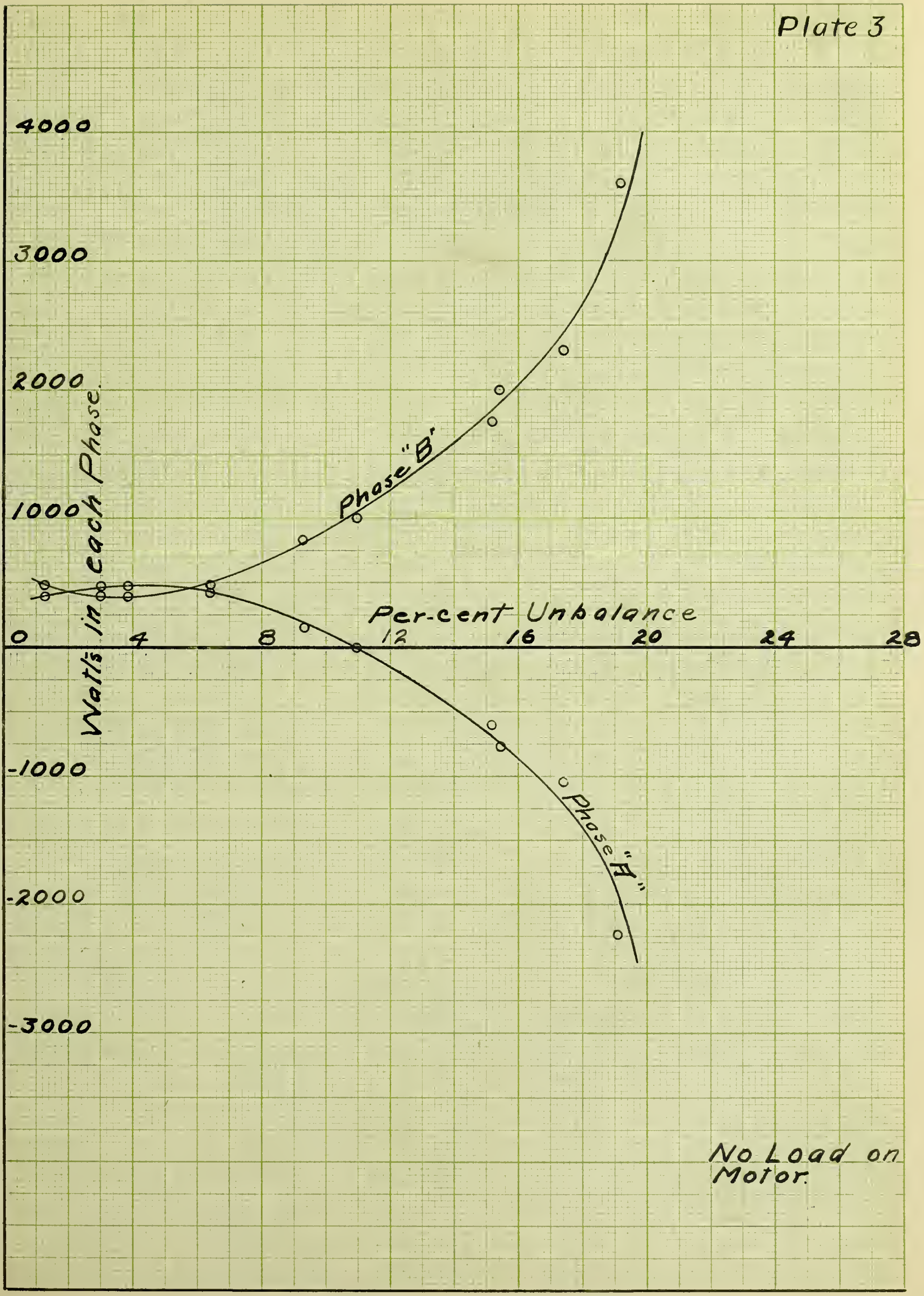

Percent Unbalance with Motor
Percent Unbalance without Motor
Full Load
65% Load
33% Load
No Load
Unbalance due to
Inductive Load
on Phase "A"
0
4
8
12
16
20
24
28
4
8
12
16
20
24
28

Plate 3



No Load on Motor.

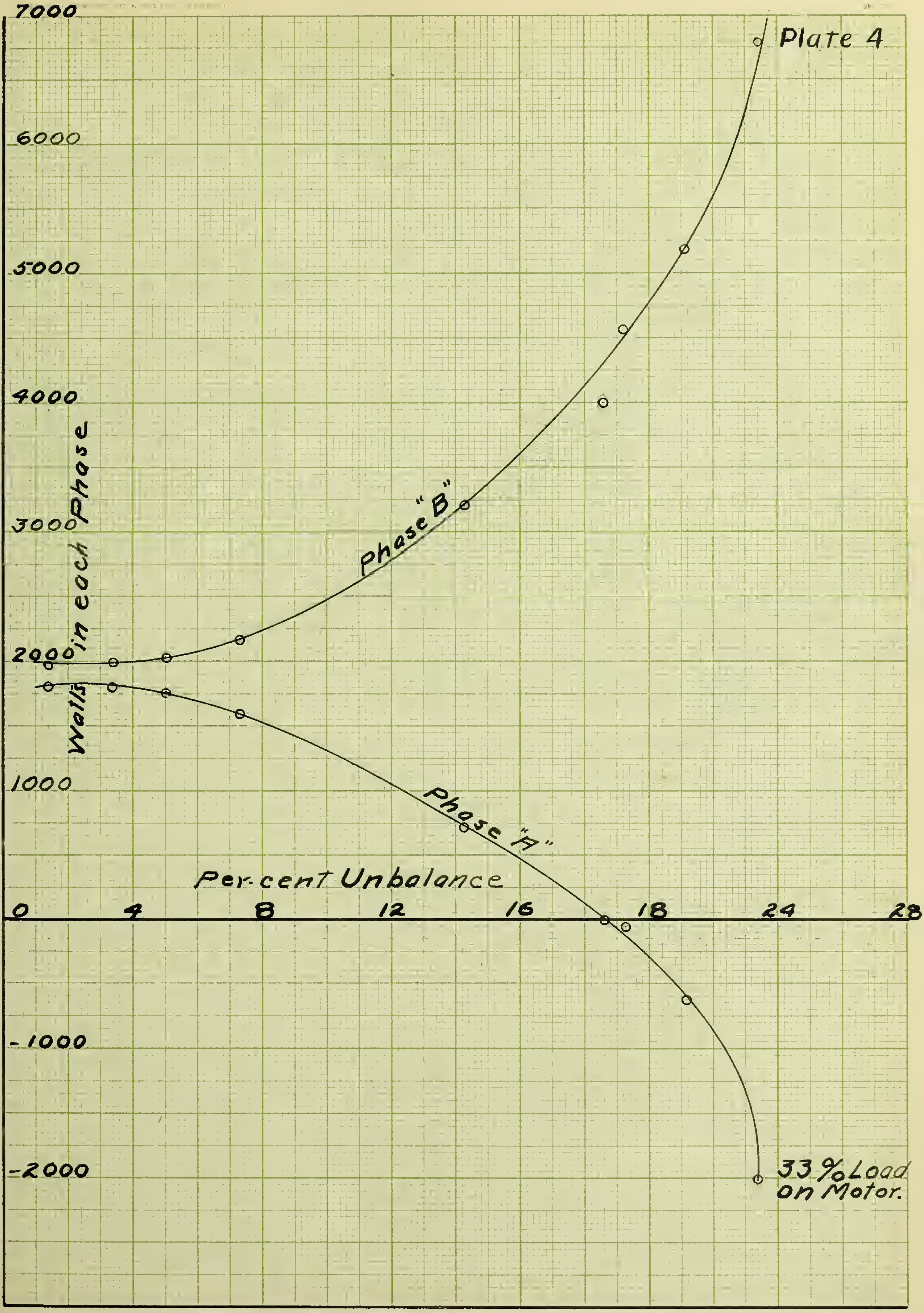


Plate 4
7000
6000
5000
4000
3000
2000
1000
-1000
-2000
Watts in each Phase
Phase "B"
Phase "A"
Per-cent Unbalance
0
4
8
12
16
18
24
28
33 % Load on Motor.

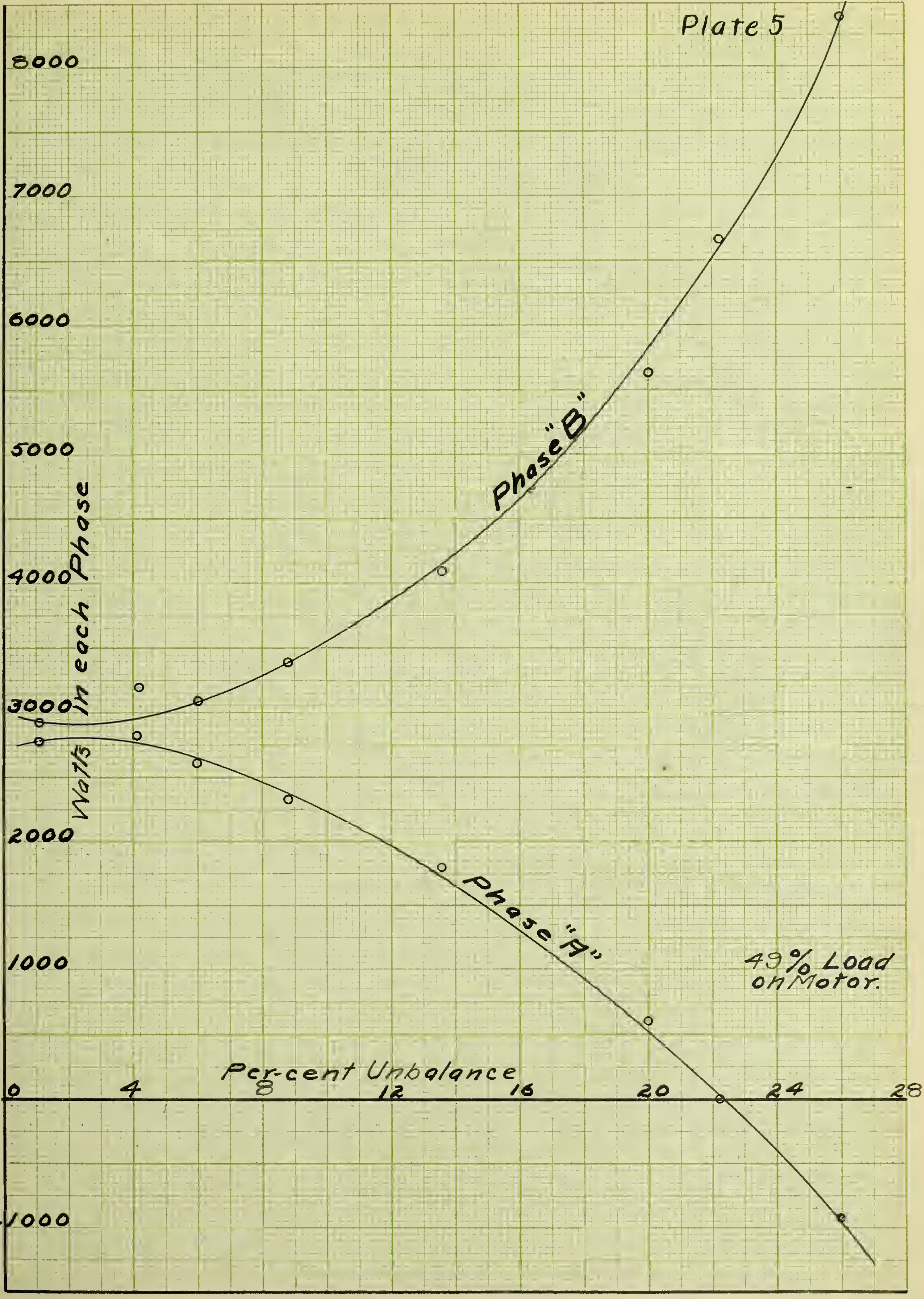


Plate 5
8000
7000
6000
5000
4000
3000
2000
1000
-1000
Watts in each Phase
Per-cent Unbalance
0
4
8
12
16
20
24
28
Phase "B"
Phase "A"
49% Load on Motor.

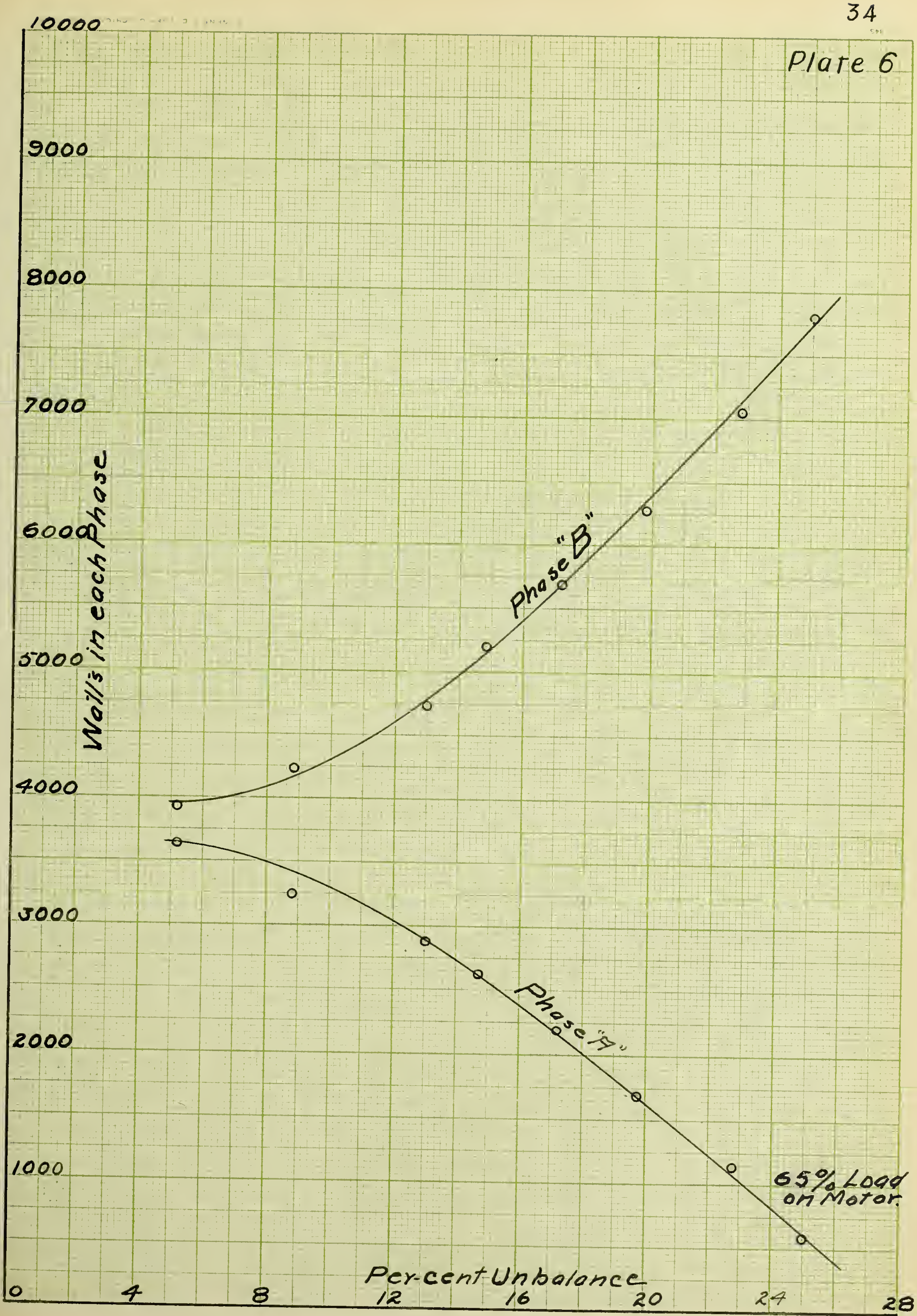


Plate 6

10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Watts in each Phase
Phase "B"
Phase "A"
65% Load on Motor.
Per-cent Unbalance
4
8
12
16
20
24
28

Plate 7

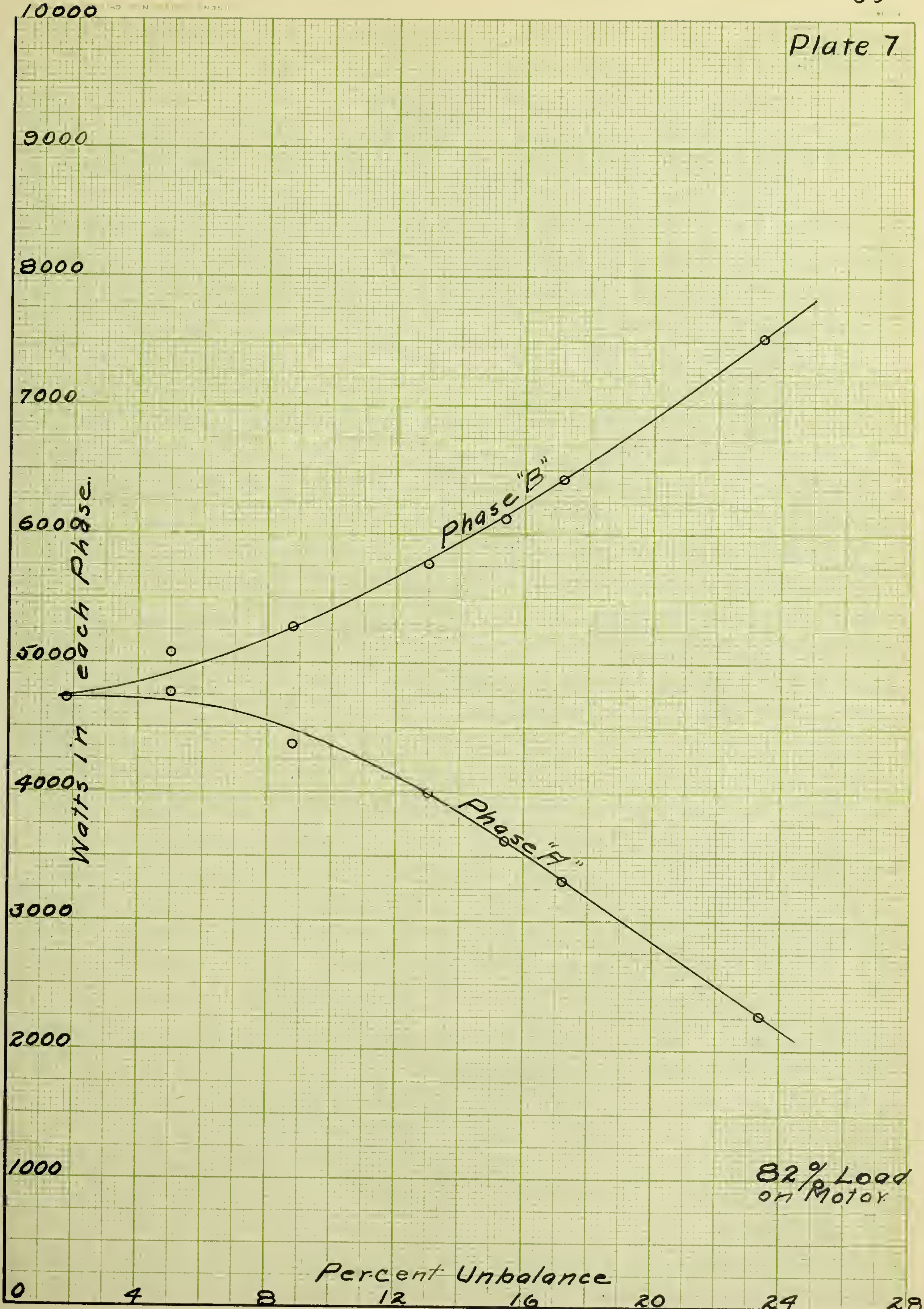

10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
4
8
12
16
20
24
28
Watts in each Phase.
Percent Unbalance
Phase "B"
Phase "A"
82% Load on Motor

Plate 8

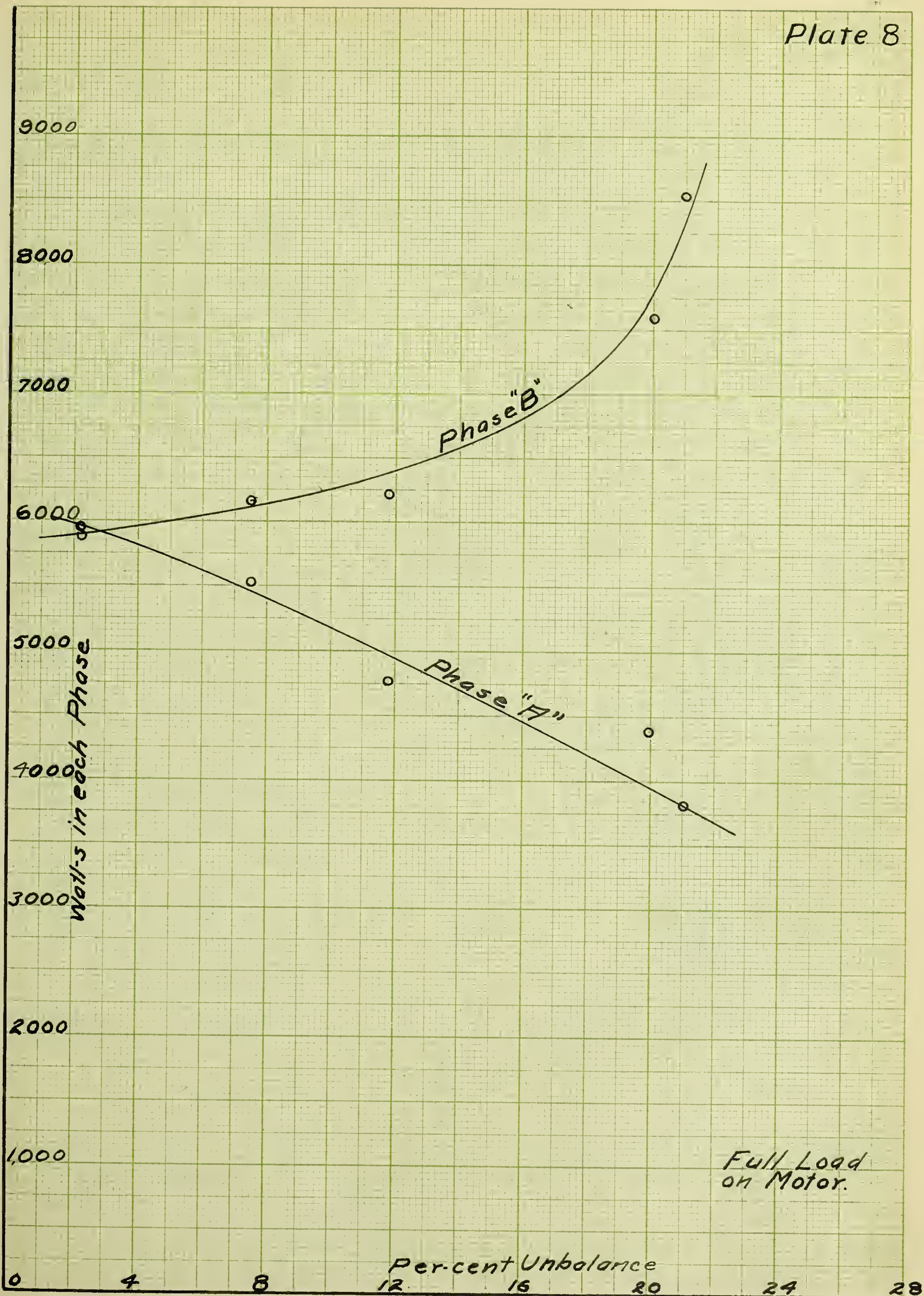
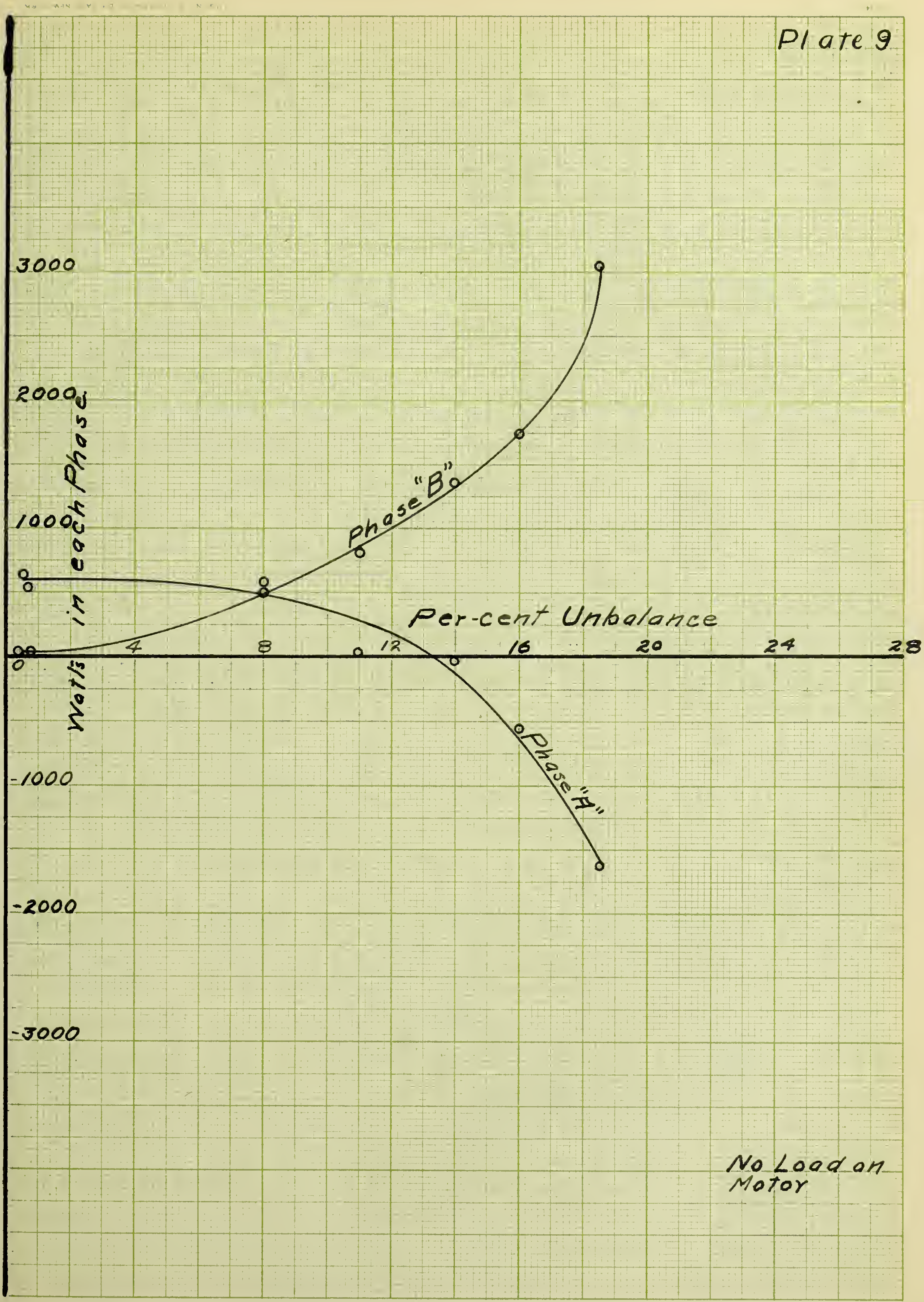
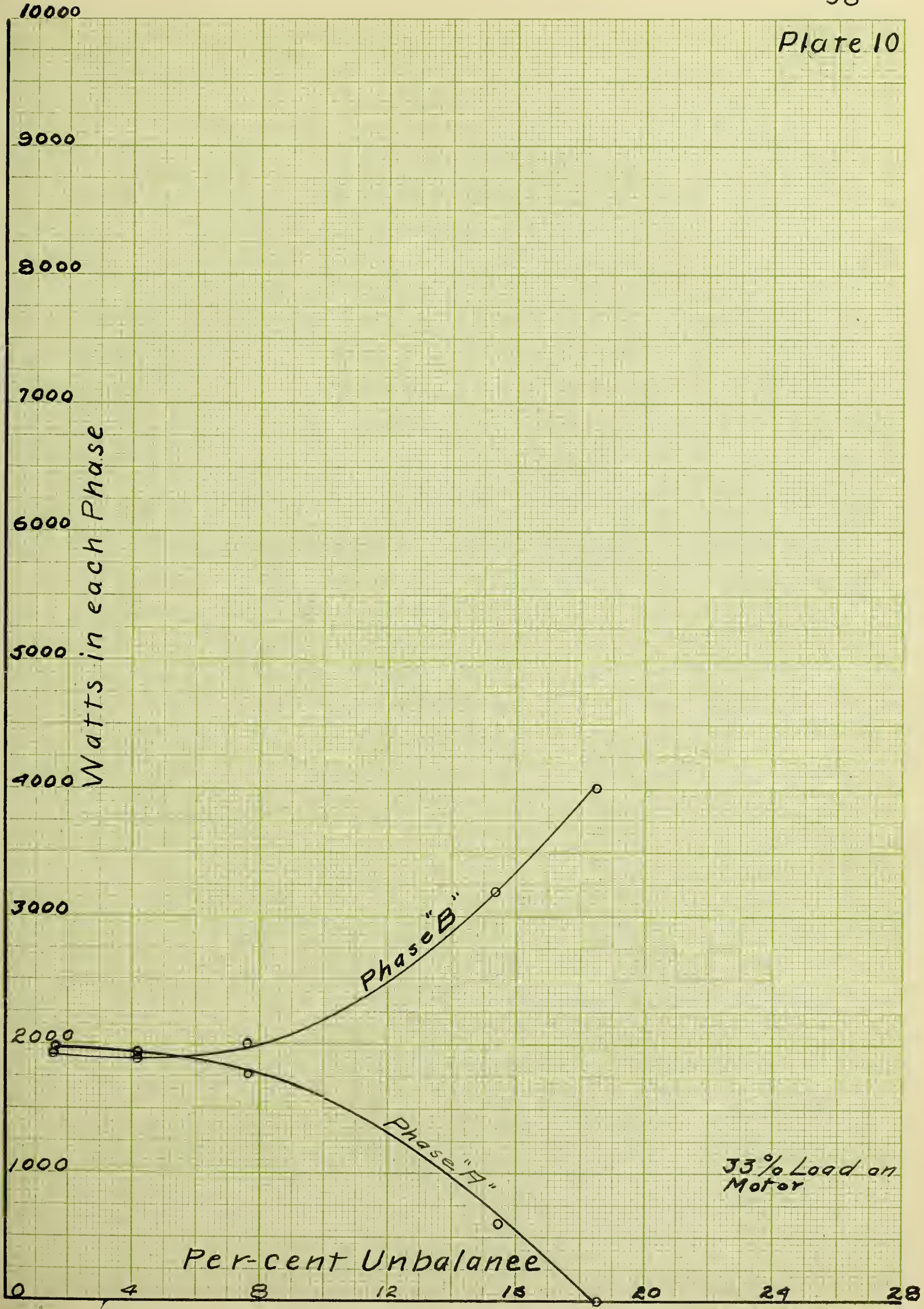

9000
8000
7000
6000
5000
4000
3000
2000
1,000
0
4
8
12
16
20
24
28
Watt-s in each Phase
Per-cent Unbalance
Phase "B"
Phase "A"
Full Load
on Motor.

Plate 9



No Load on Motor

Plate 10



33% Load on Motor

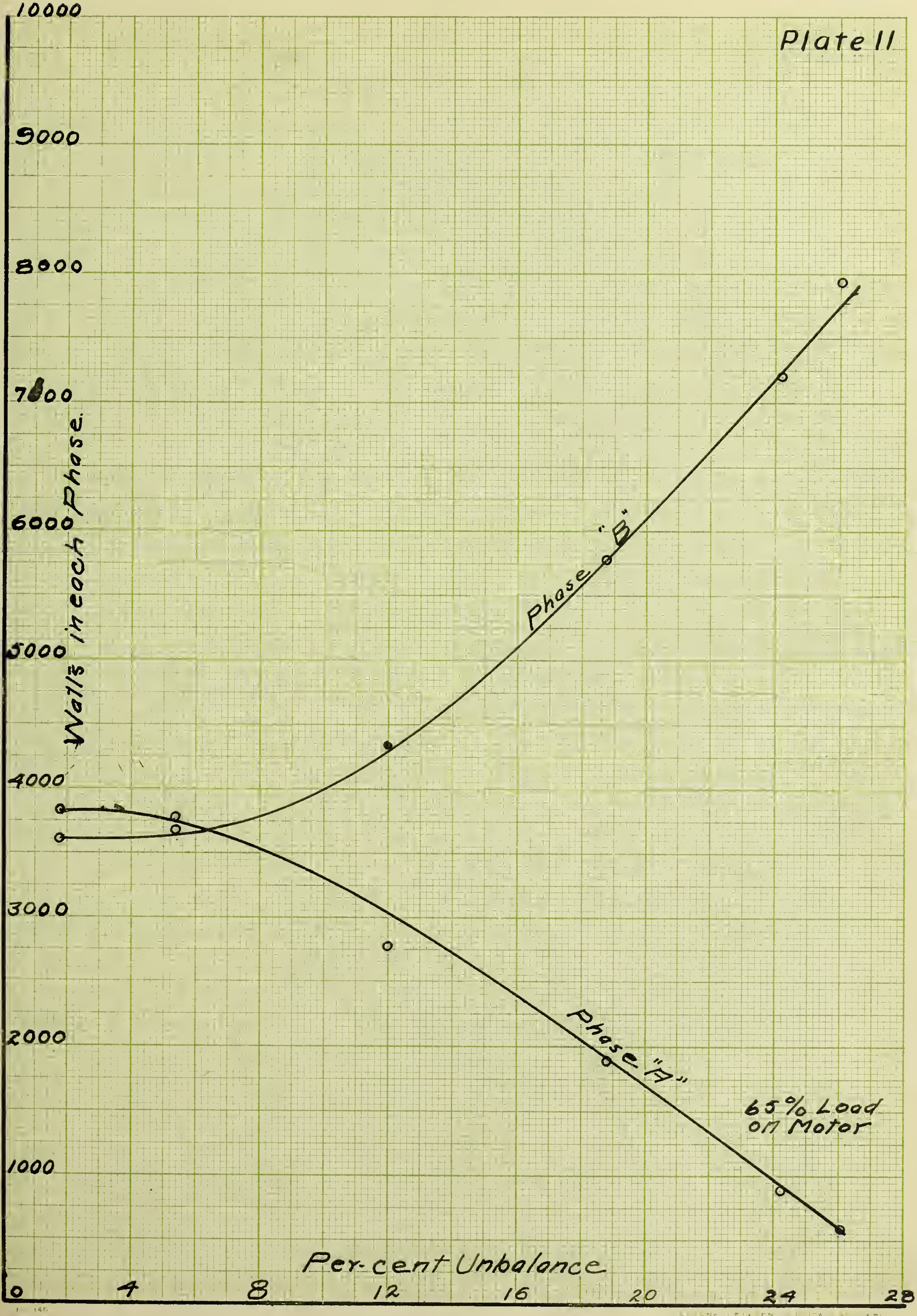


Plate II

10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
Watts in each Phase
0
4
8
12
16
20
24
28
Per-cent Unbalance
Phase "B"
Phase "A"
65% Load on Motor

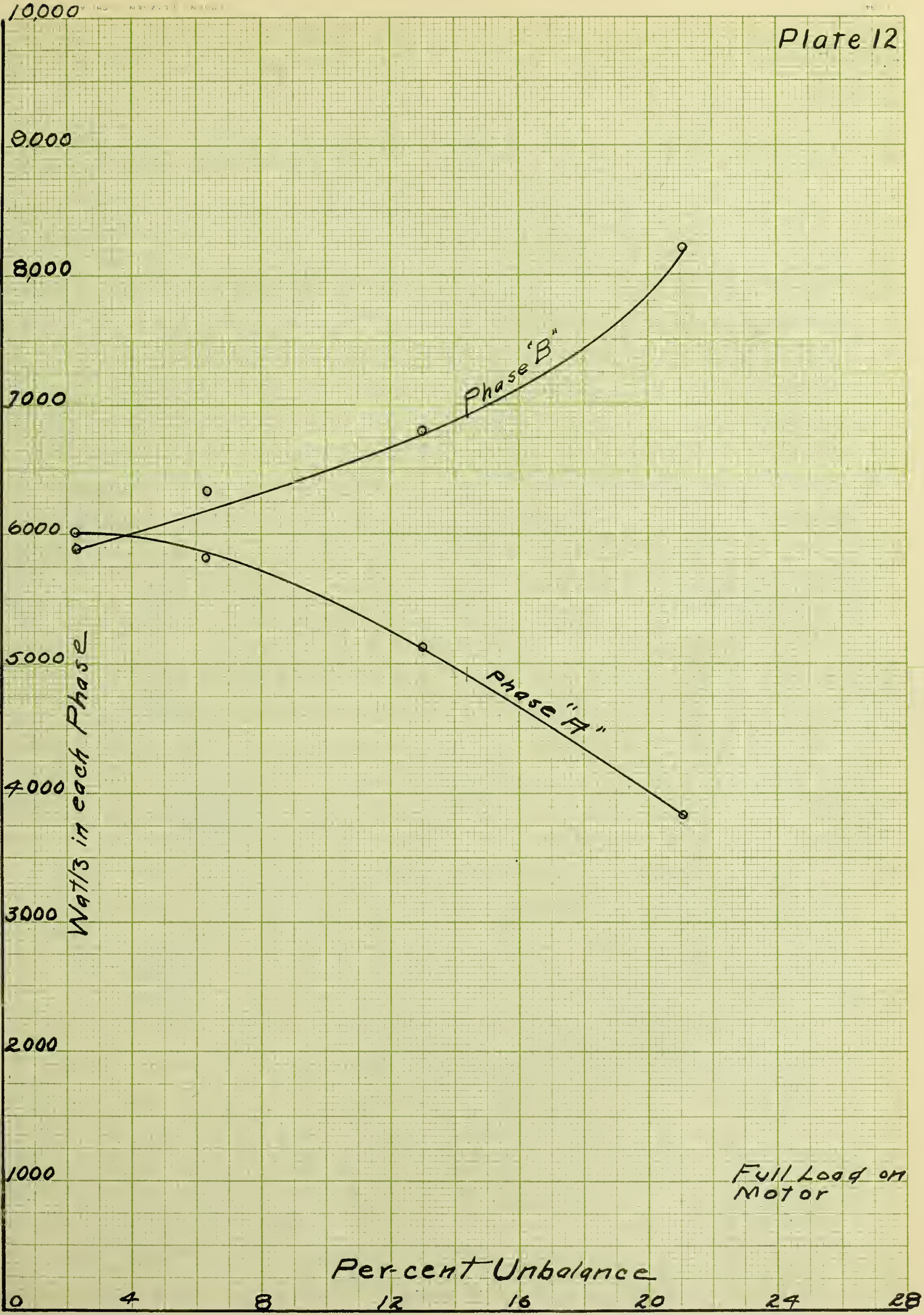


Plate 12
10,000
9,000
8,000
7000
6000
5000
4000
3000
2000
1000
0
4
8
12
16
20
24
28
Watts in each Phase
Per-cent Unbalance
Phase "B"
Phase "A"
Full Load on Motor

Plate 13

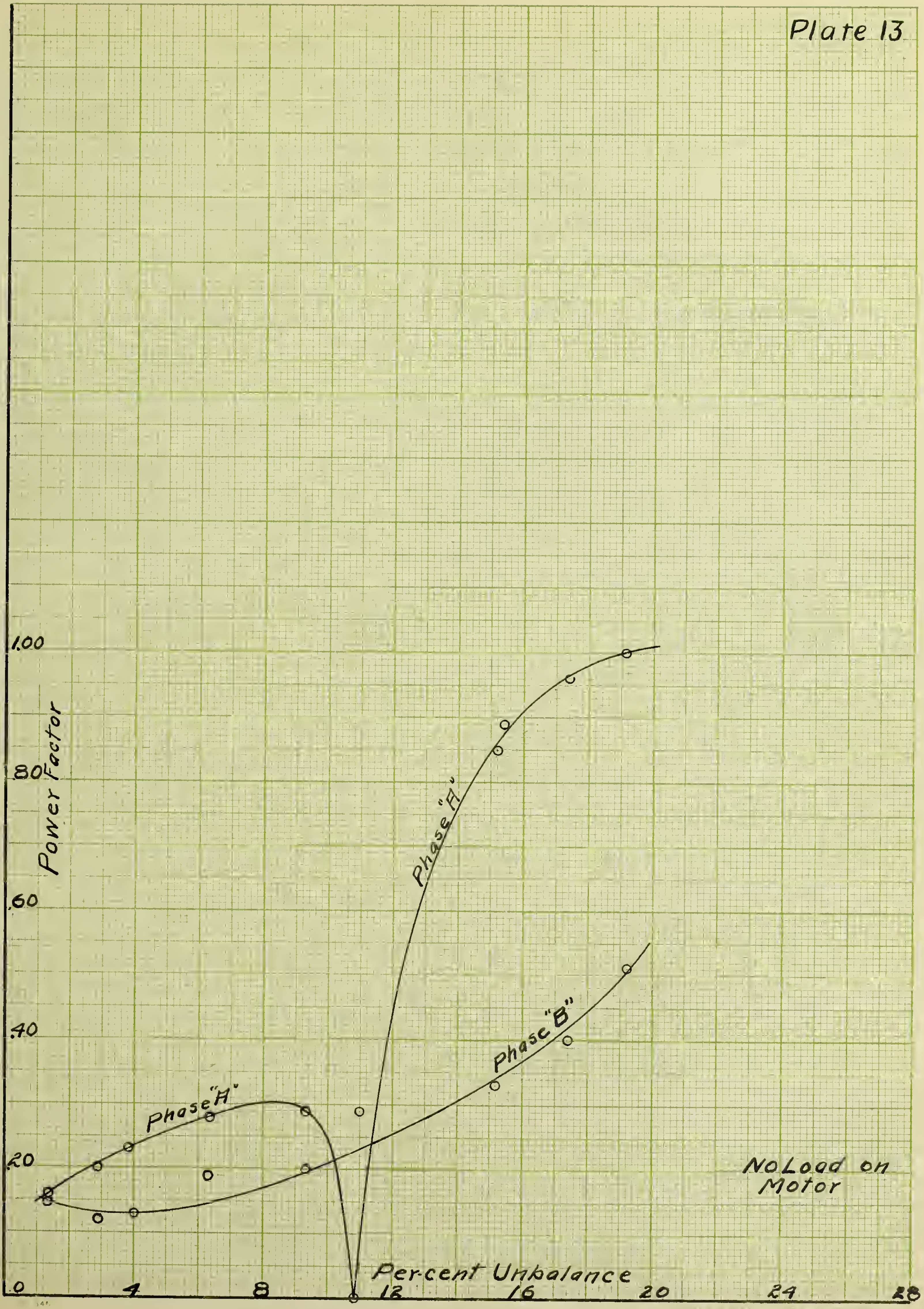

Power Factor
1.00
.80
.60
.40
.20
0
4
8
12
16
20
24
28
Percent Unbalance
Phase "A"
Phase "A"
Phase "B"
No Load on Motor

Plate 14

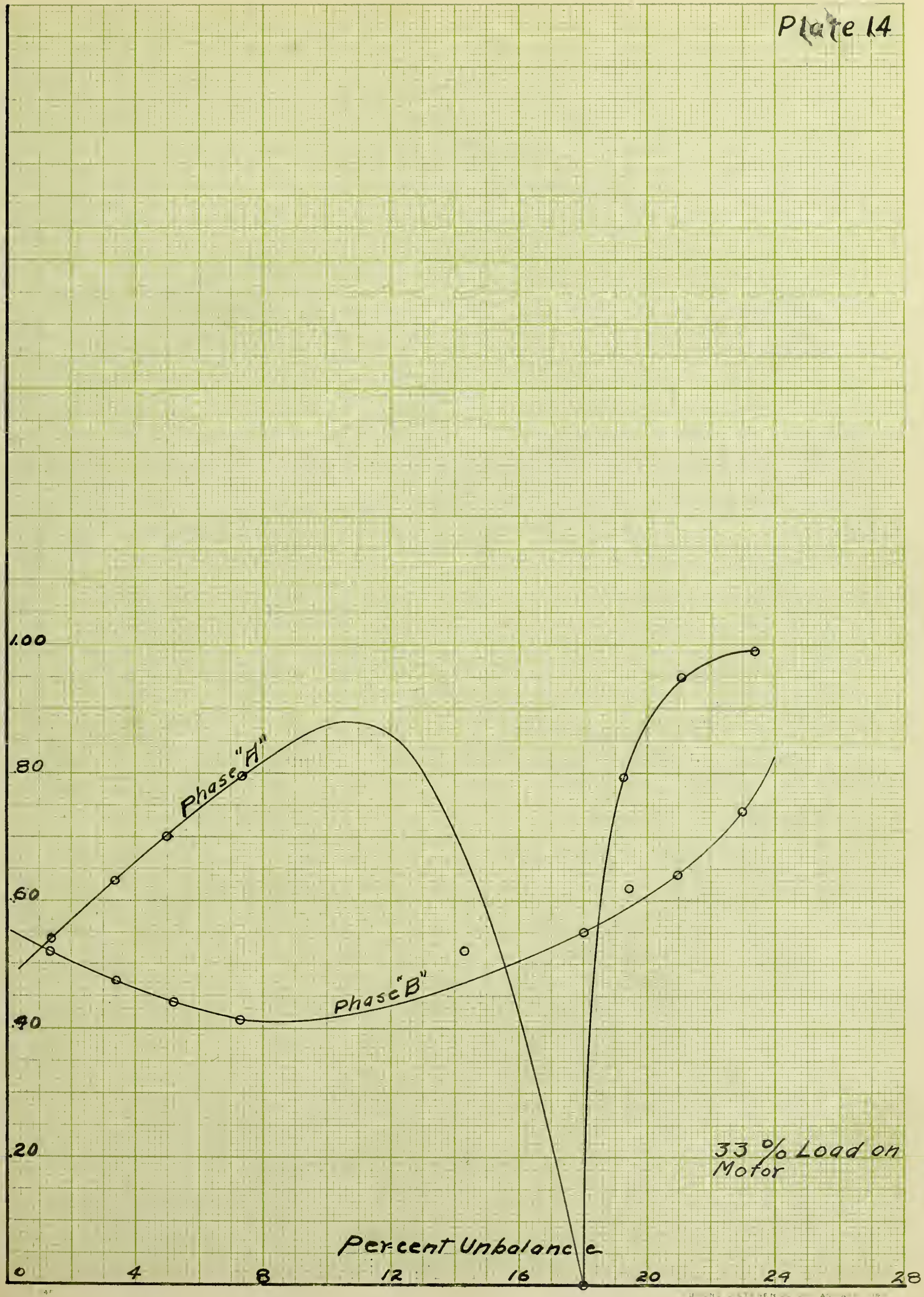
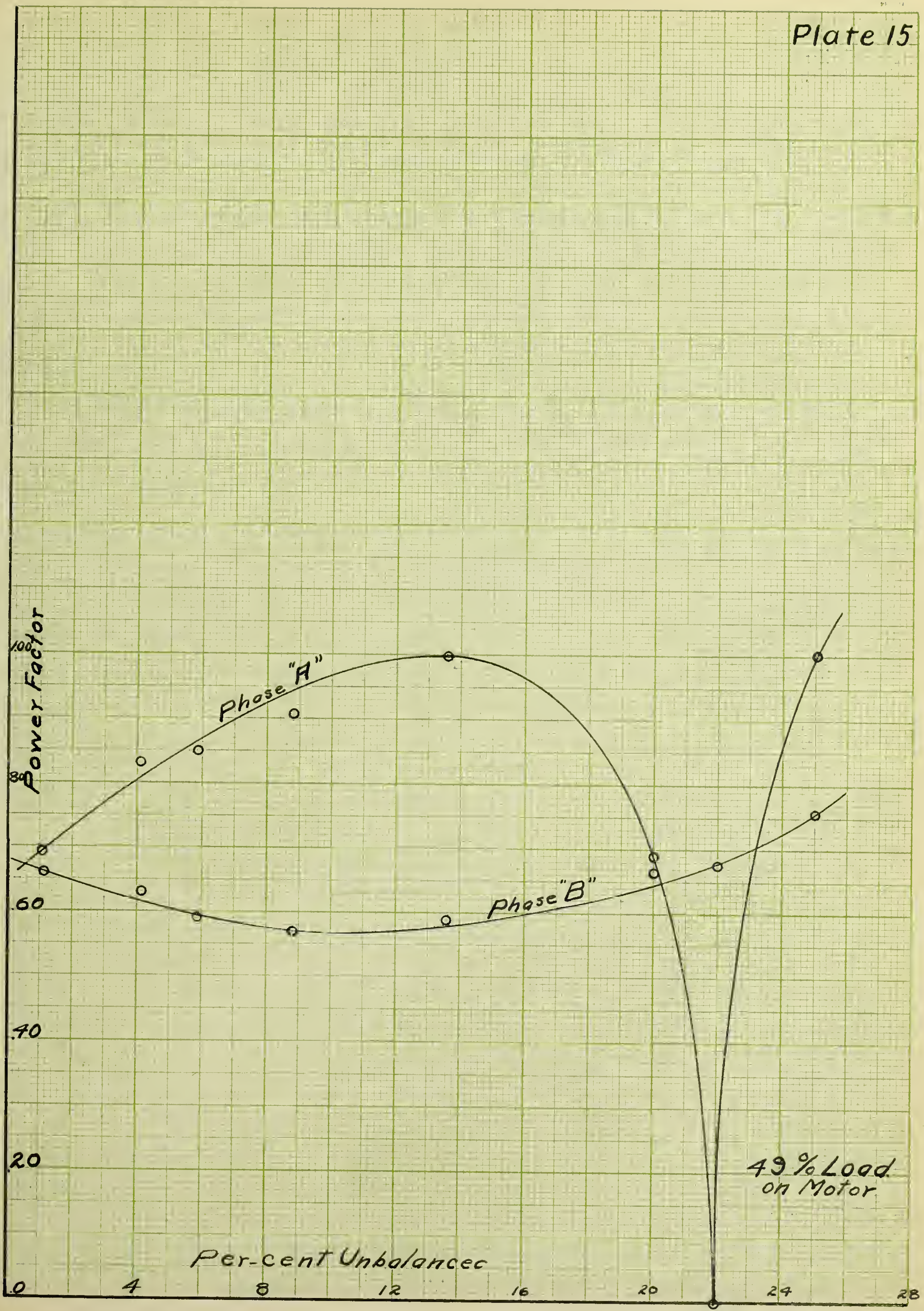

1.00
.80
.60
.40
.20
0
4
8
12
16
20
24
28
Phase "A"
Phase "B"
Percent Unbalance
33 % Load on Motor

Plate 15


Power Factor
1.00
.80
.60
.40
.20
Phase "A"
Phase "B"
49 % Load on Motor
Per-cent Unbalancec
0
4
8
12
16
20
24
28

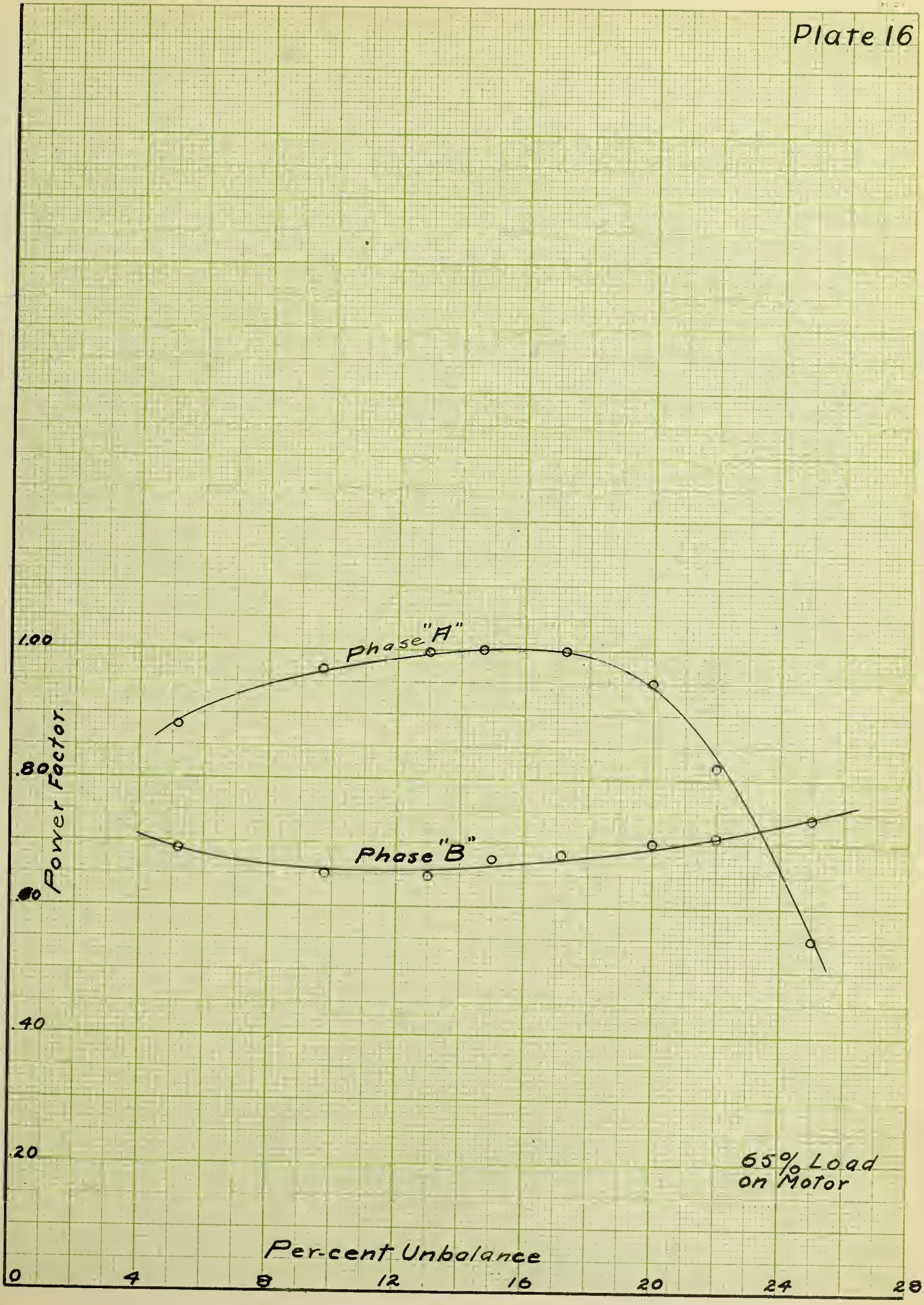


Plate 16
1.00
.80
.60
.40
.20
Power Factor.
Phase "A"
Phase "B"
65% Load on Motor
Per-cent Unbalance
0
4
8
12
16
20
24
28

Plate 17

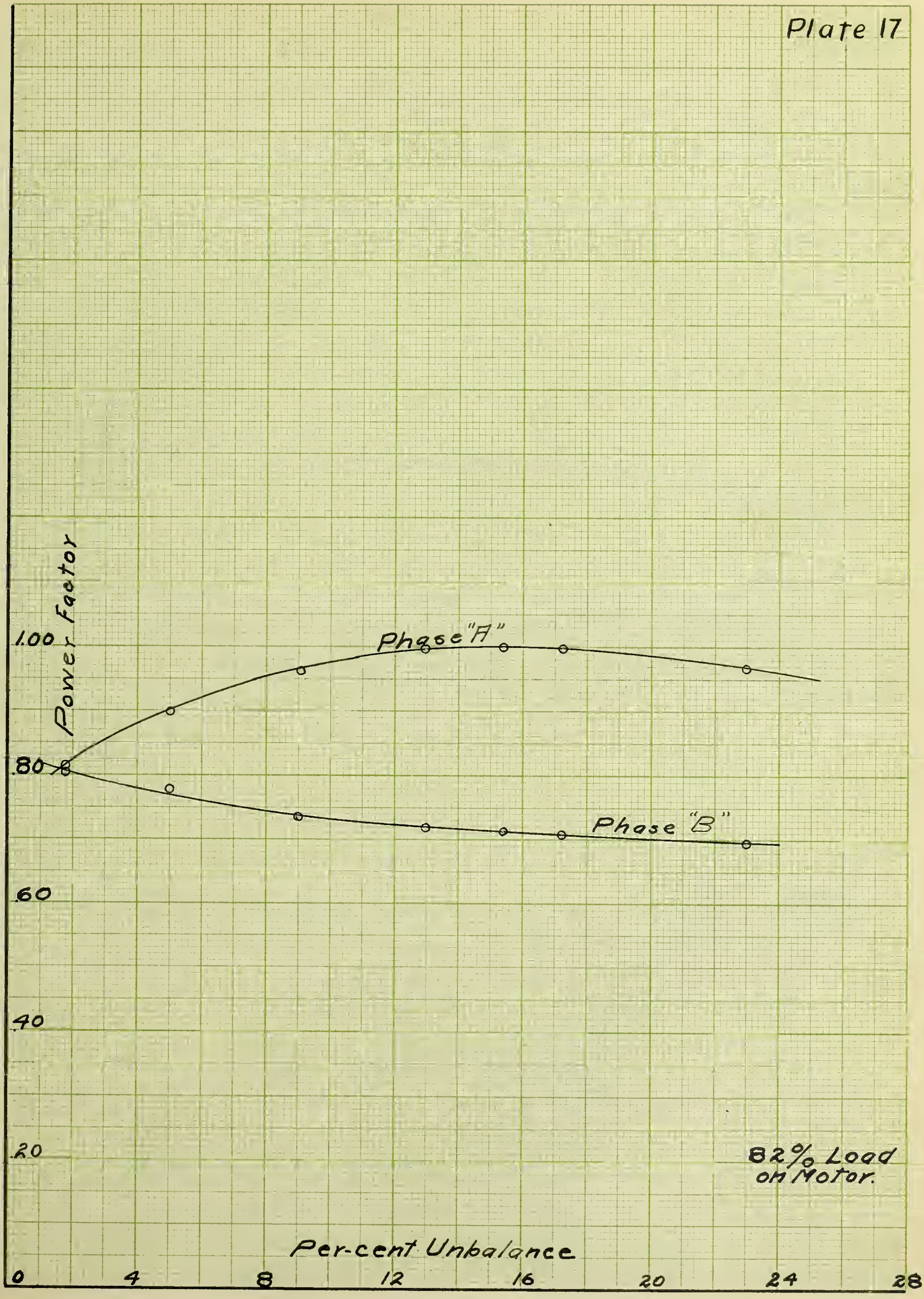
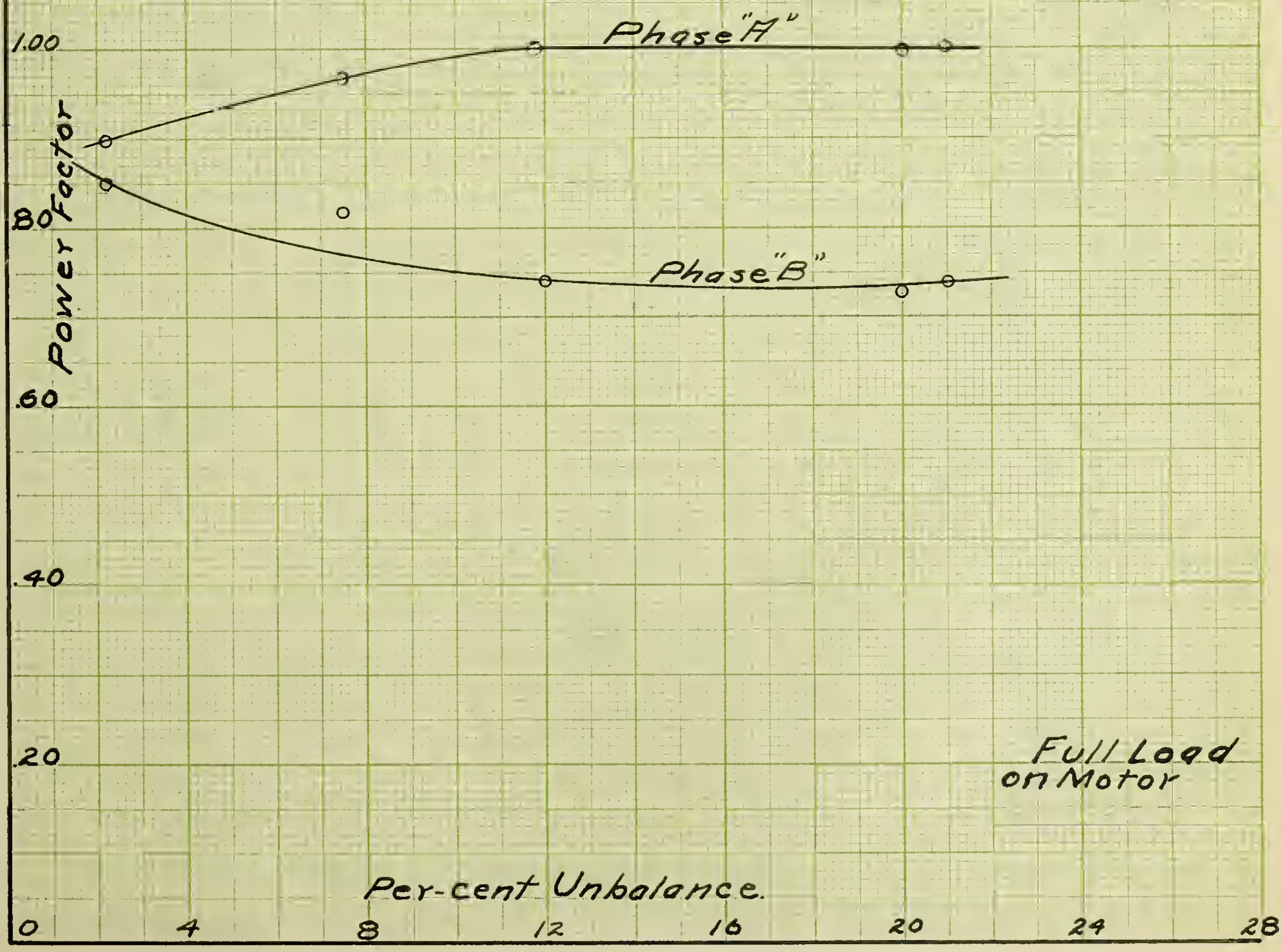

Power Factor
1.00
.80
.60
.40
.20
Phase "A"
Phase "B"
82% Load on Motor.
Per-cent Unbalance
0
4
8
12
16
20
24
28

Plate 18


Phase "A"
Phase "B"
Power Factor
1.00
.80
.60
.40
.20
Per-cent Unbalance.
0
4
8
12
16
20
24
28
Full Load on Motor

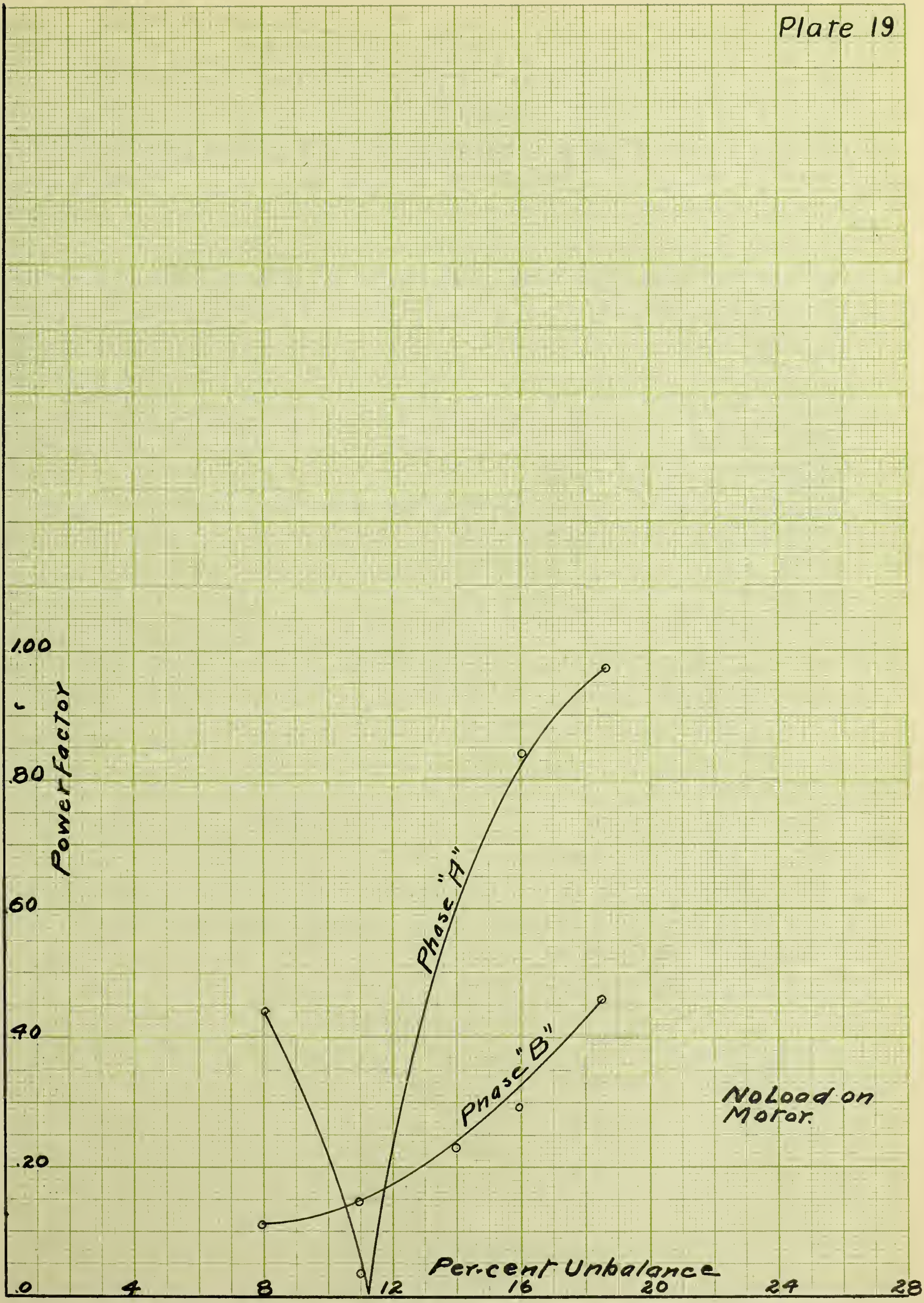


Plate 19
Power Factor
1.00
.80
.60
.40
.20
.0
4
8
12
16
20
24
28
Per-cent Unbalance
Phase "A"
Phase "B"
No Load on Motor.

Plate 20

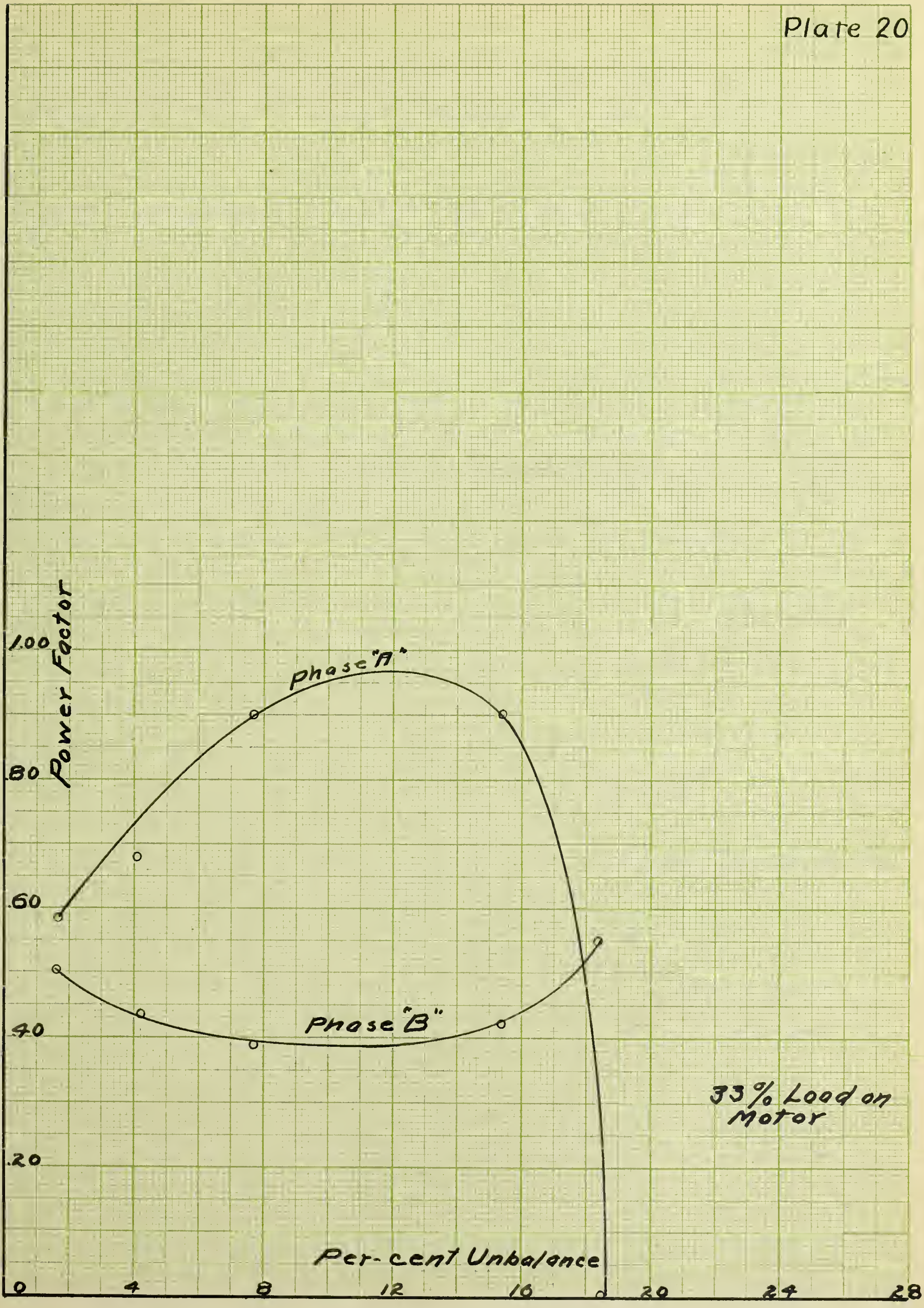

Power Factor
1.00
.80
.60
.40
.20
Phase "A"
Phase "B"
33% Load on Motor
Per-cent Unbalance
0
4
8
12
16
20
24
28

Plate 21

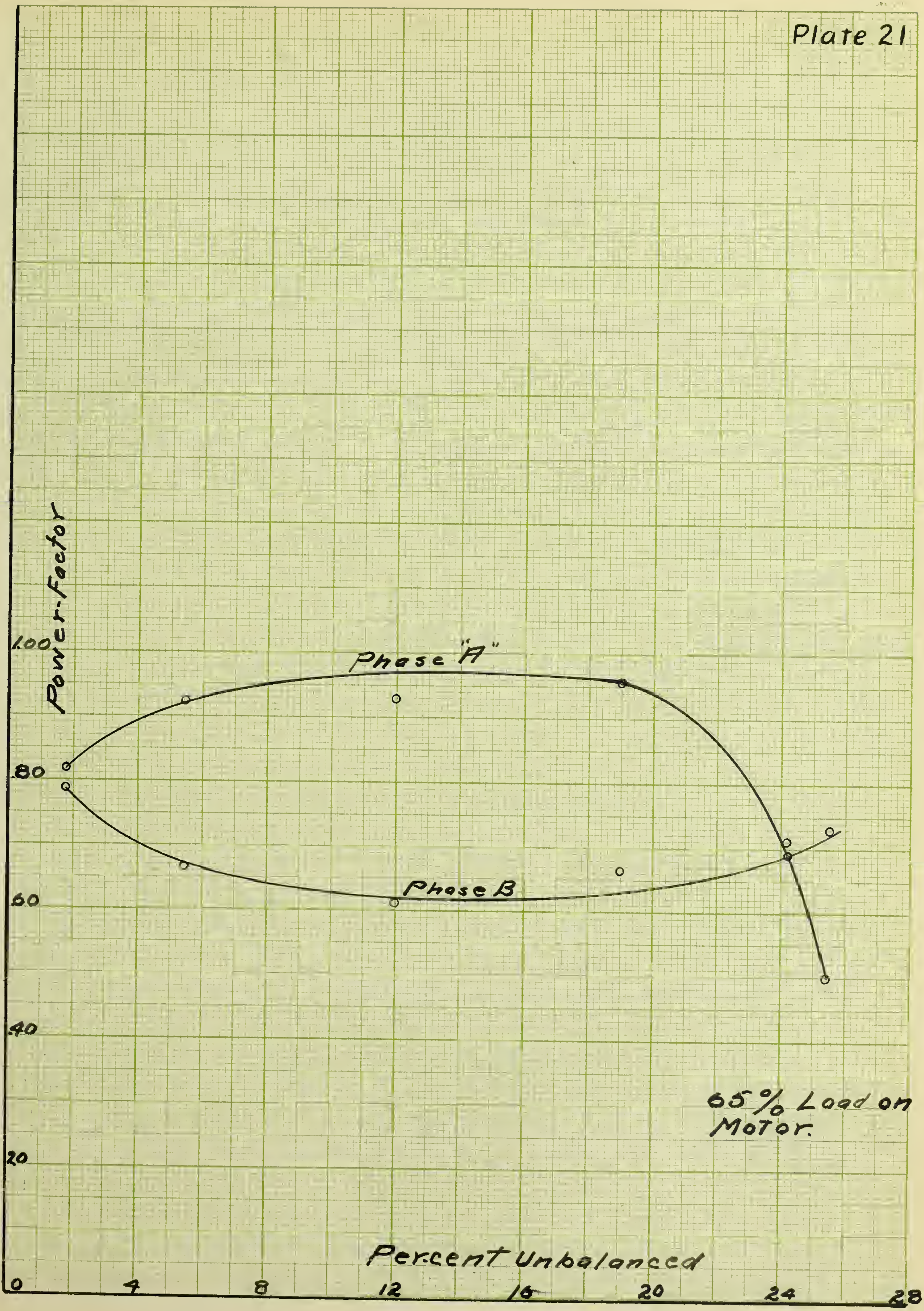

Power-Factor
1.00
.80
.60
.40
.20
0
4
8
12
16
20
24
28
Phase "A"
Phase B
Percent Unbalanced
65% Load on Motor.

Plate 22

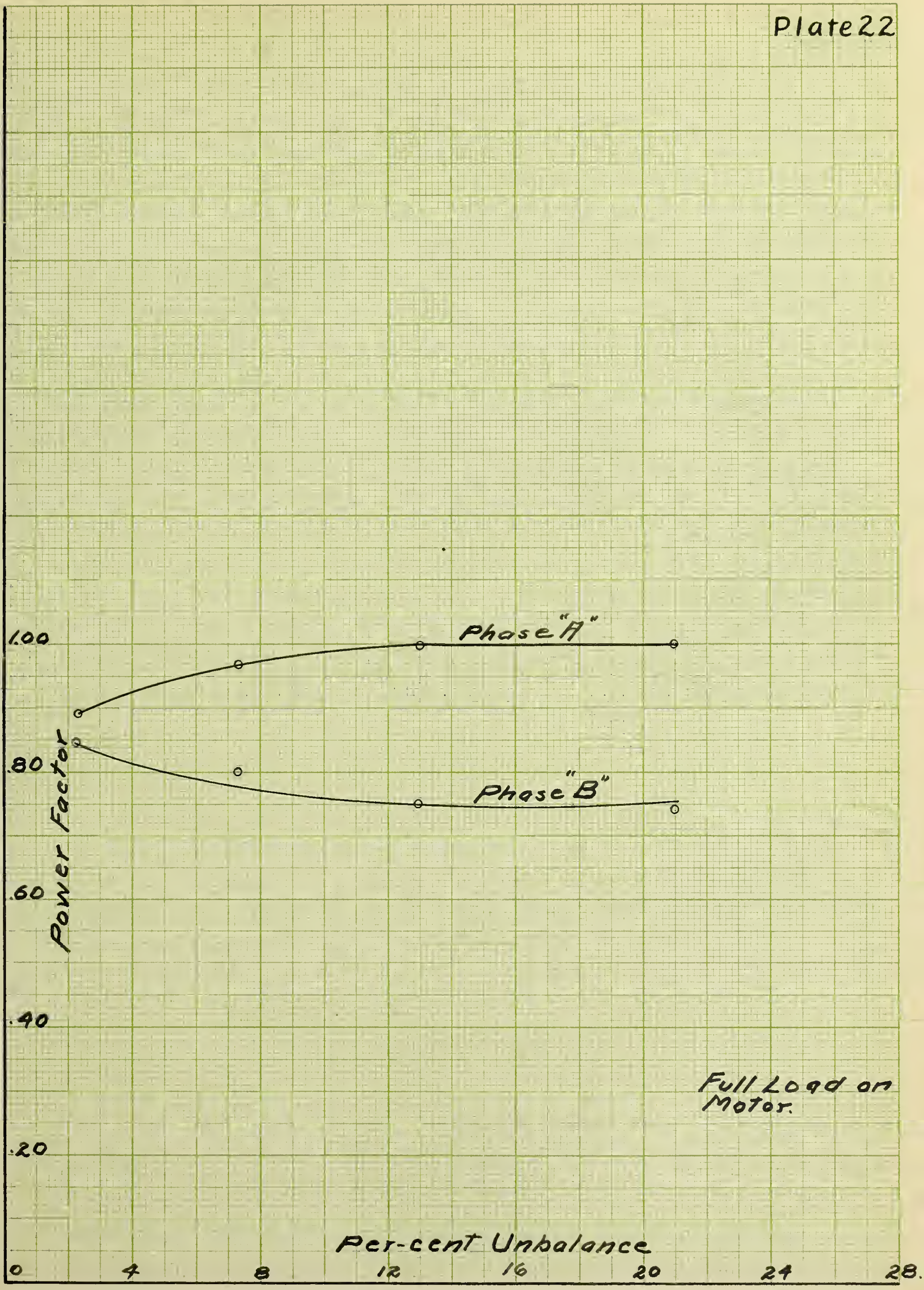

Phase "A"
Phase "B"
Power Factor
1.00
.80
.60
.40
.20
0
4
8
12
16
20
24
28.
Per-cent Unbalance
Full Load on Motor.

Plate 23

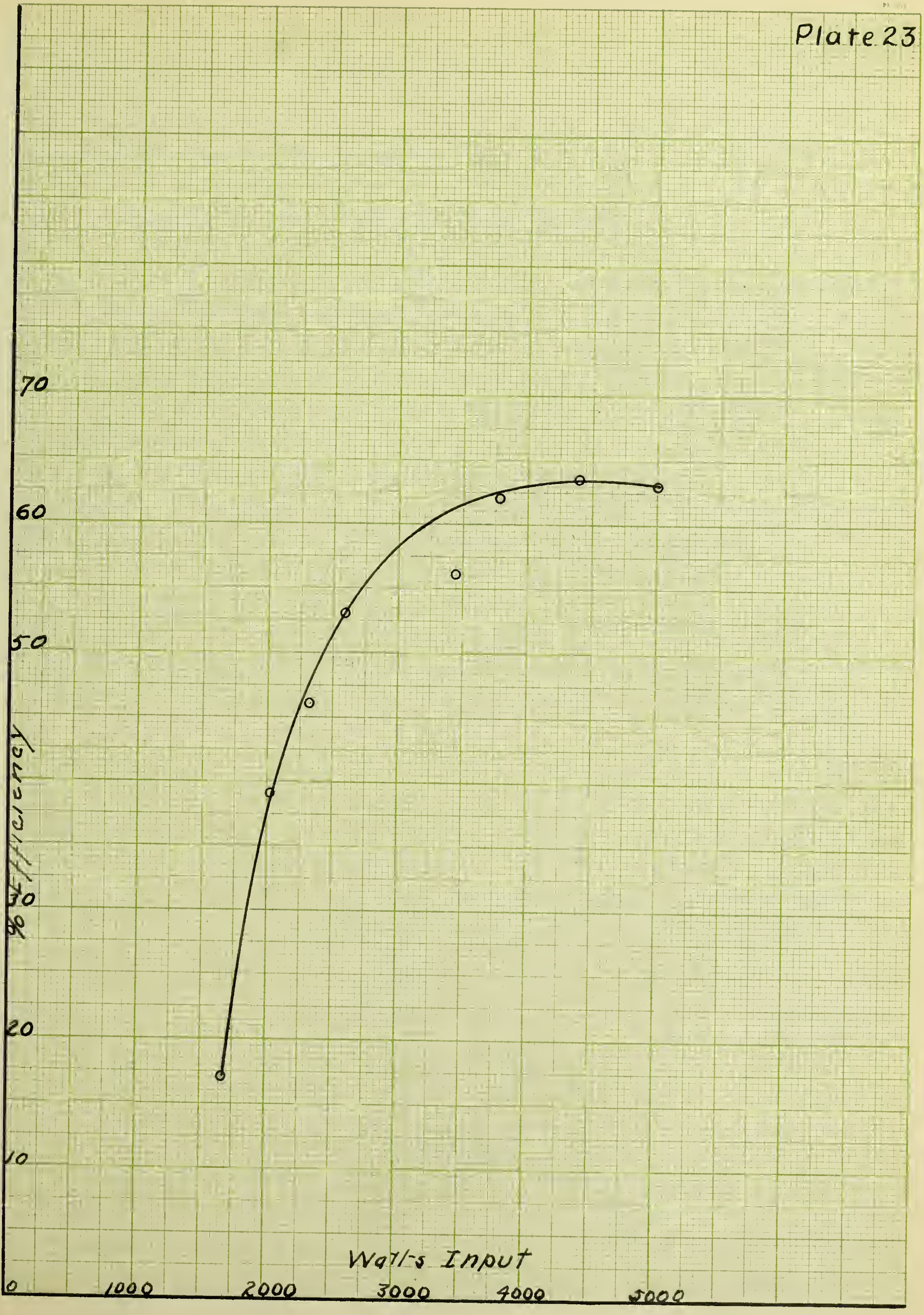

70
60
50
30
20
10
0
Efficiency %
1000
2000
3000
4000
5000
Watts Input

Plate 24

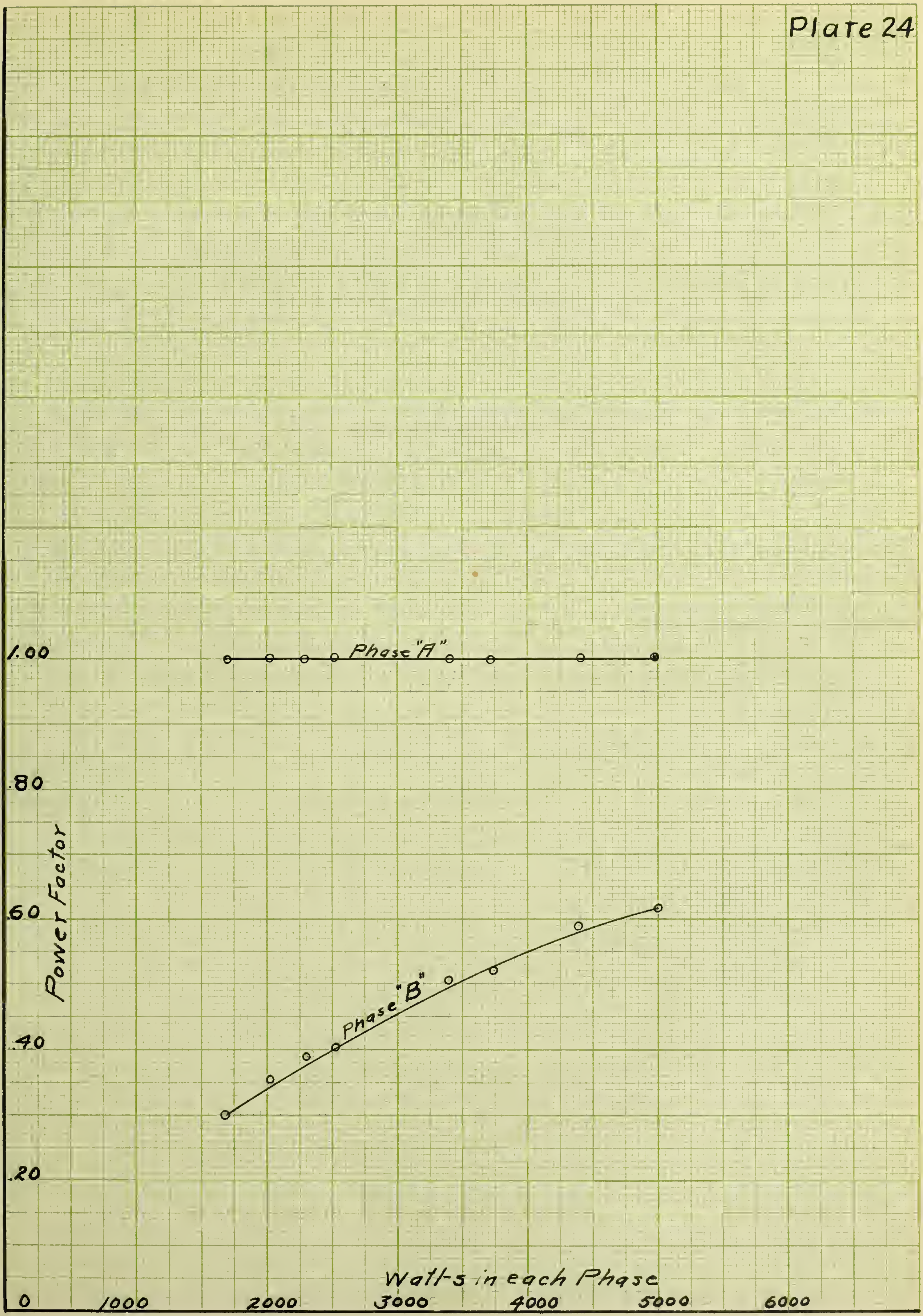

Power Factor
1.00
.80
.60
.40
.20
0
1000
2000
3000
4000
5000
6000
Watts in each Phase
Phase "A"
Phase "B"

Plate 25

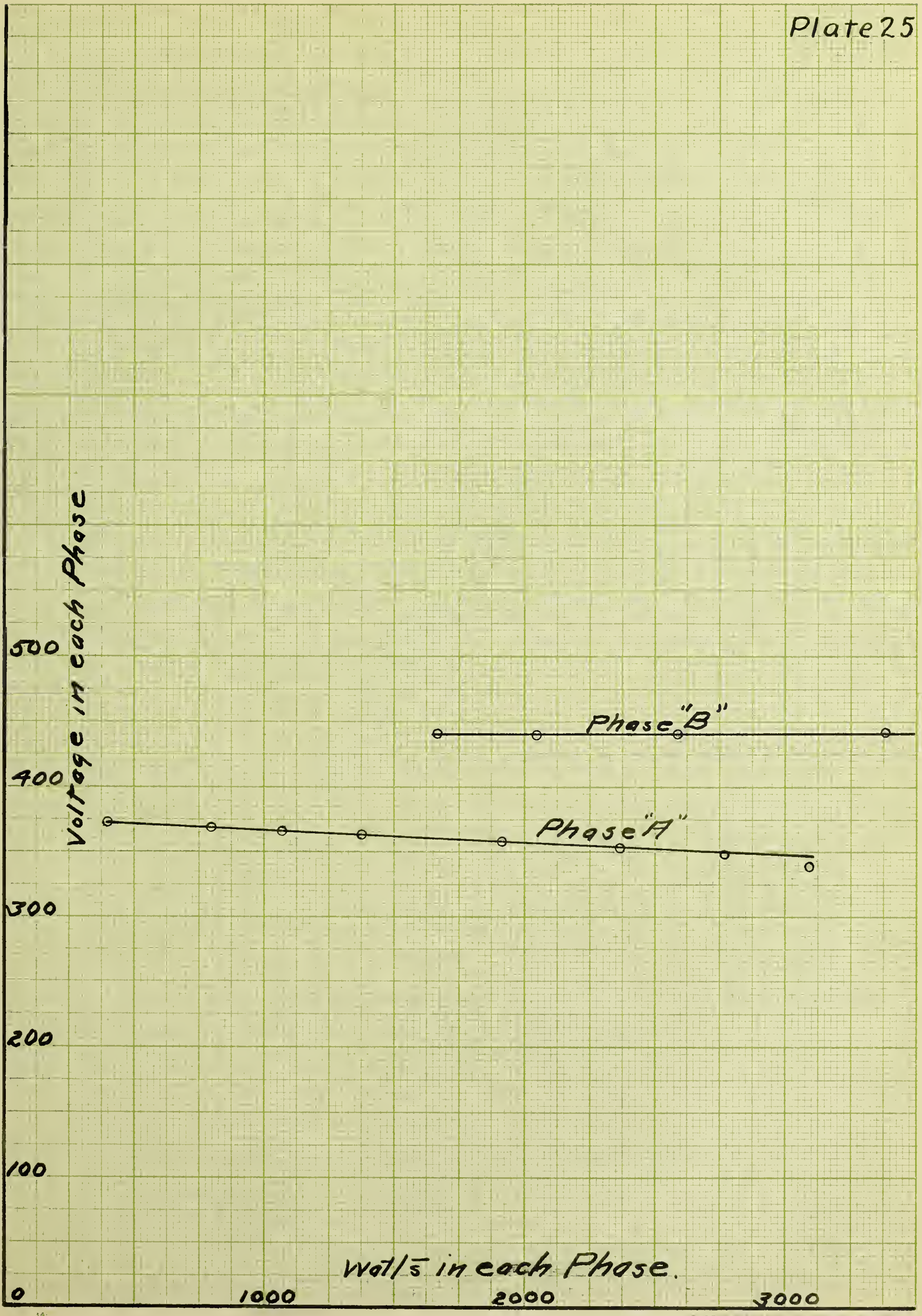

Voltage in each Phase
500
400
300
200
100
0
1000
2000
3000
Watts in each Phase.
Phase "B"
Phase "A"

Plate 26

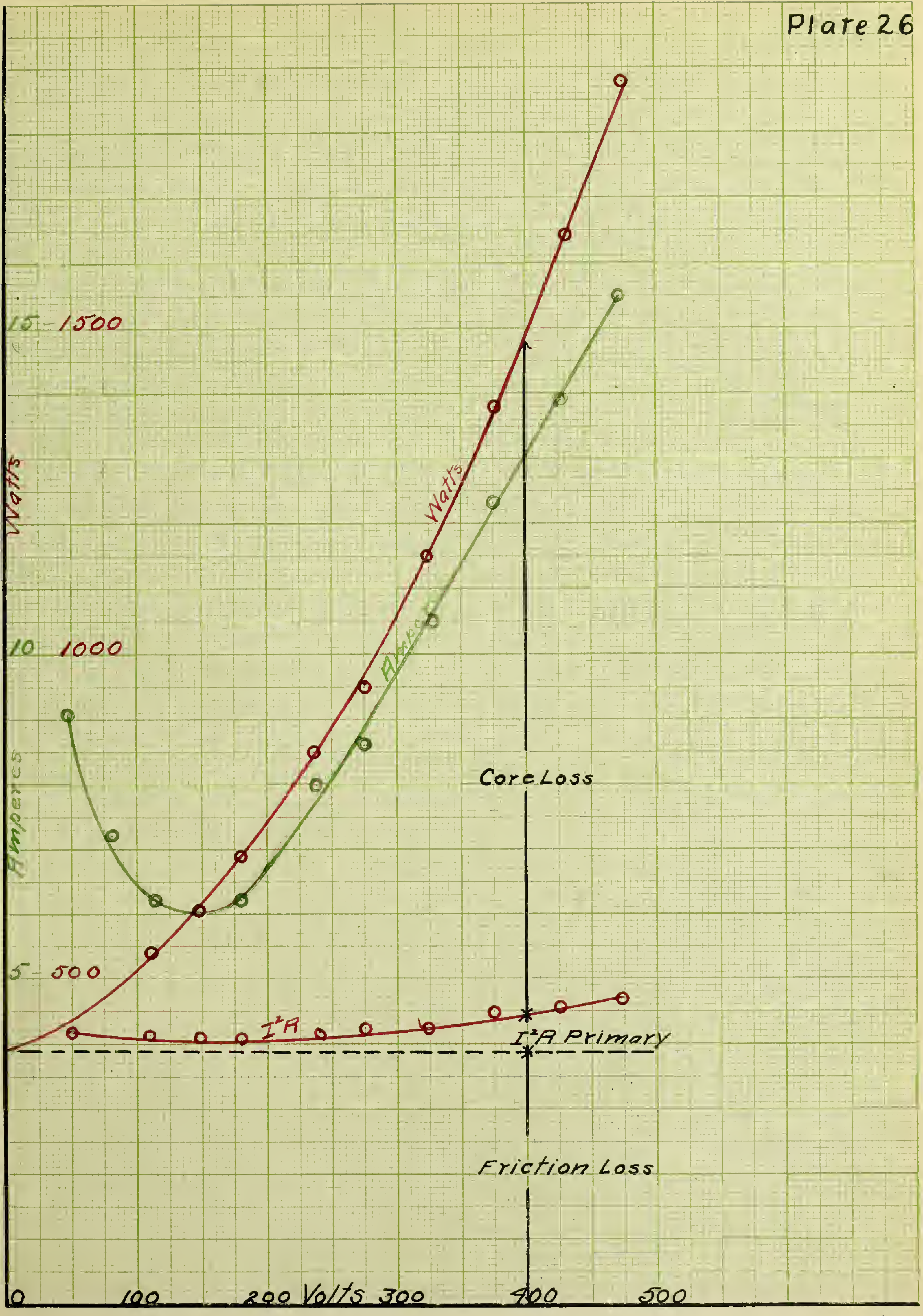

Watts
Amperes
15 – 1500
10 1000
5 – 500
0
100
200
Volts
300
400
500
Watts
Amps
I²R
I²R Primary
Core Loss
Friction Loss

Plate 27

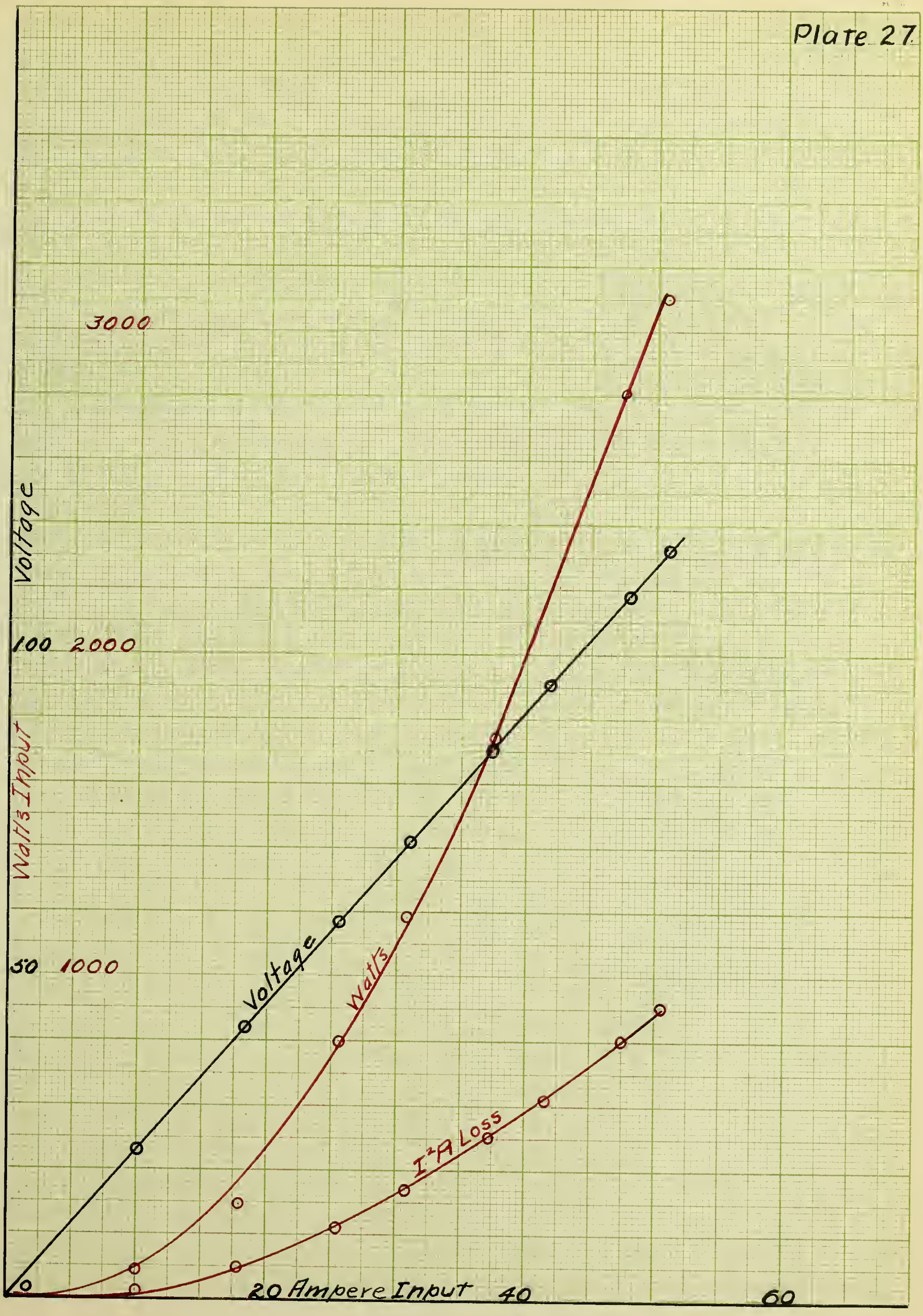

3000
Voltage
100
2000
Watts Input
50
1000
Voltage
Watts
I²R Loss
0
20 Ampere Input
40
60

Plate 28

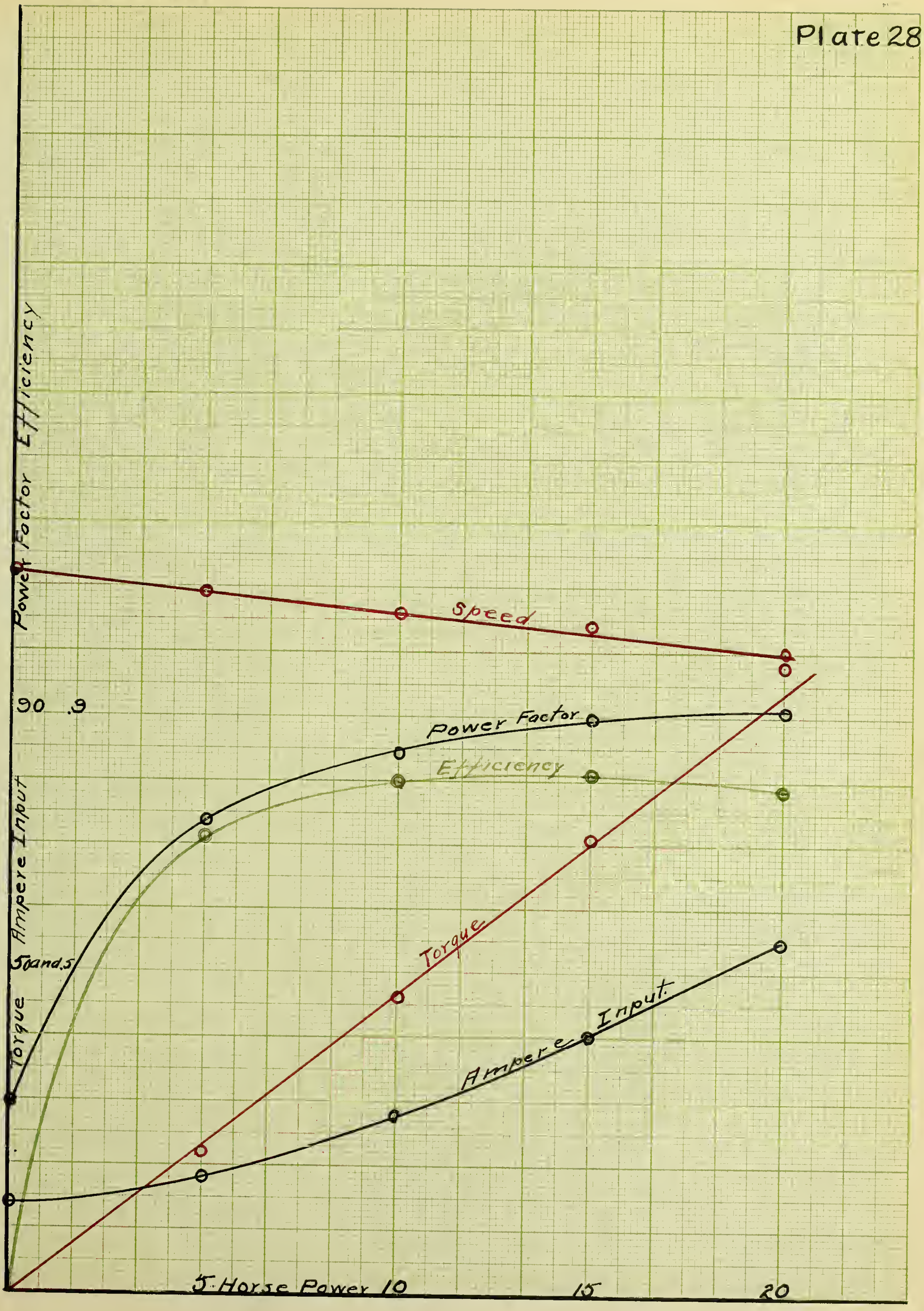
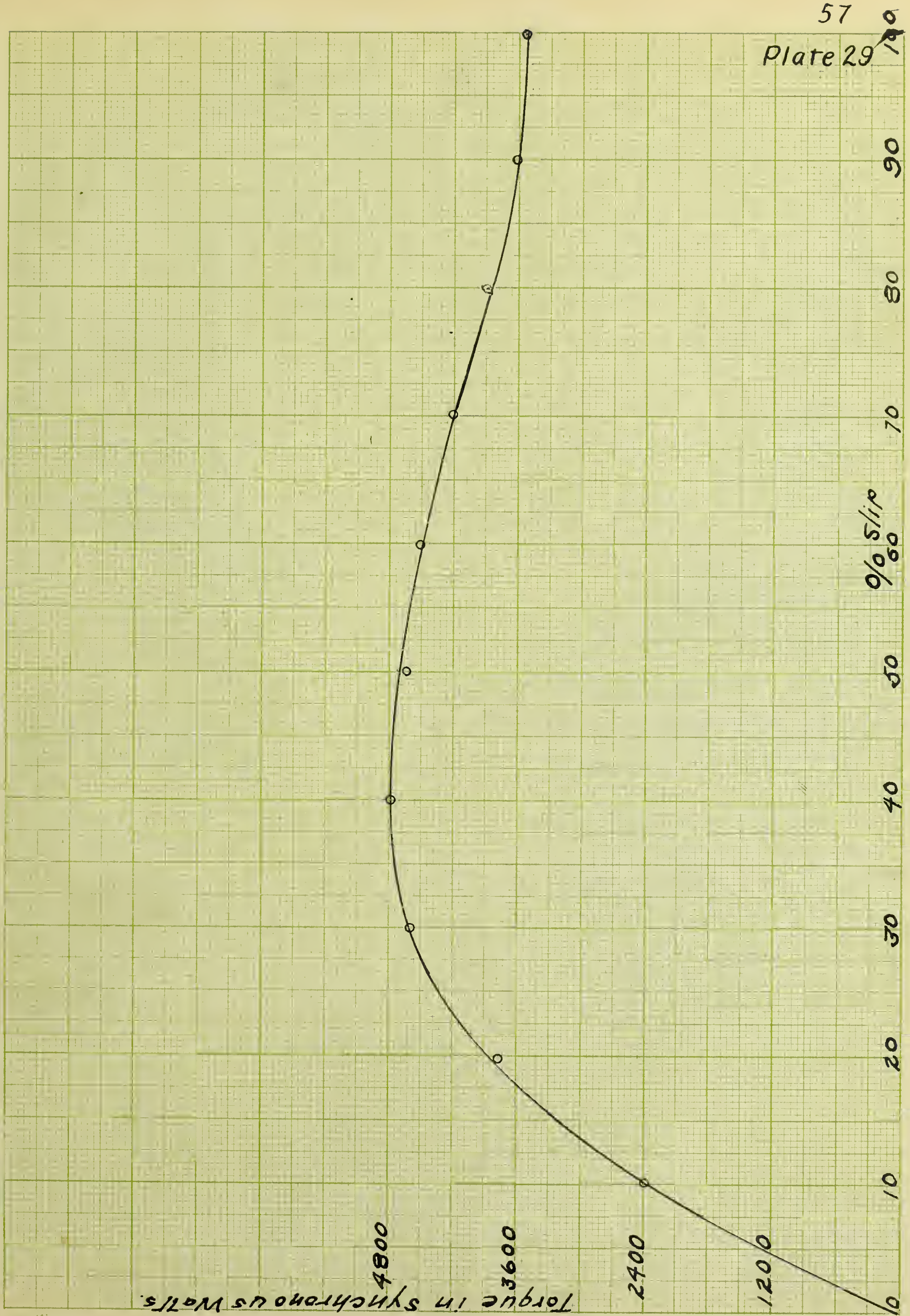
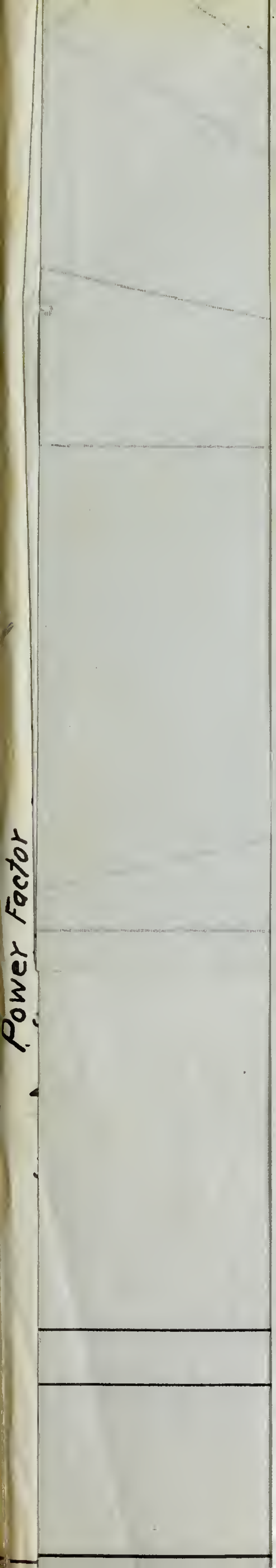
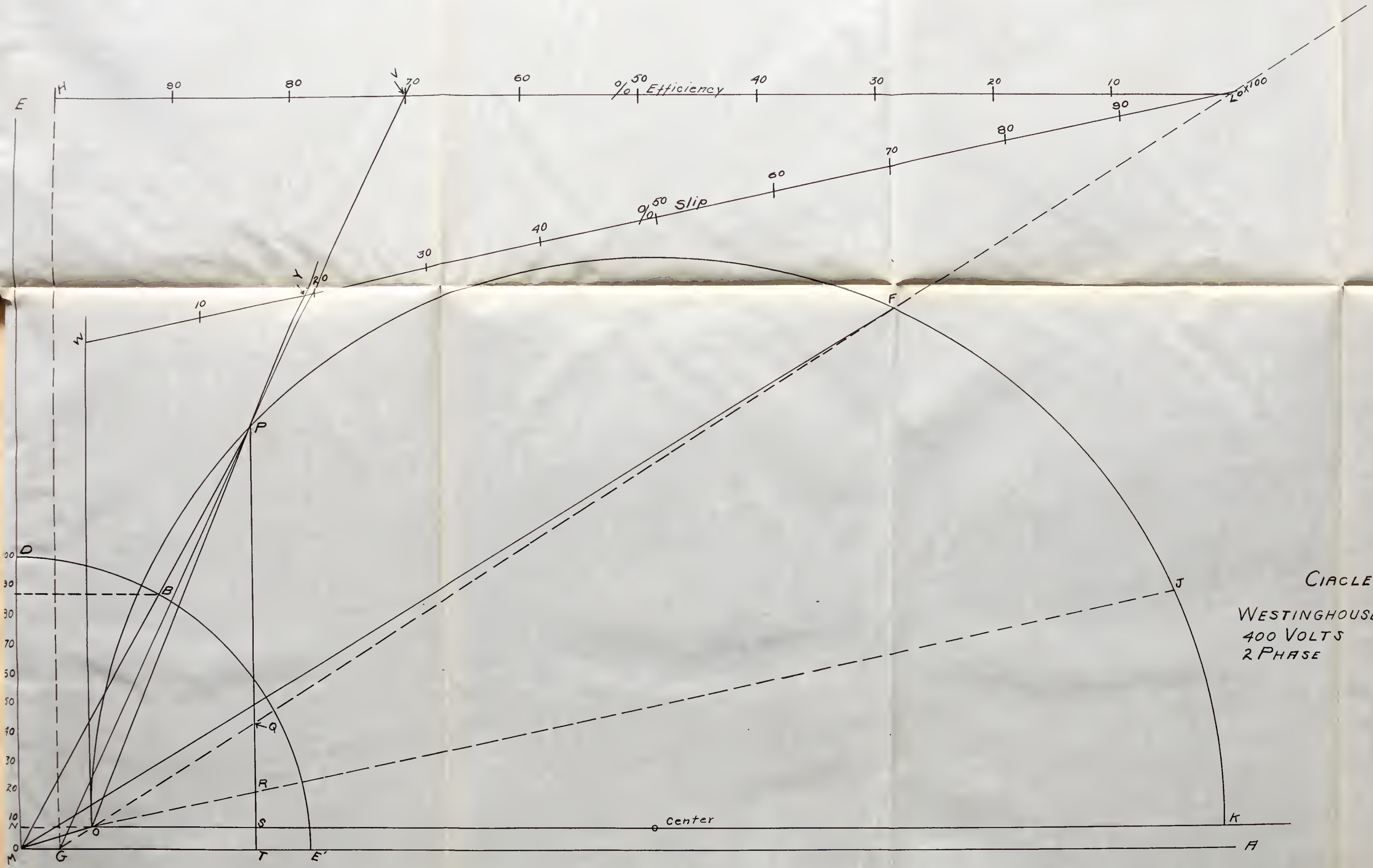

Power Factor Efficiency
Speed
90 .9
Power Factor
Efficiency
Ampere Input
Torque
50 and .5
Torque
Ampere Input.
5 Horse Power 10
15
20

Plate 29


Torque in synchronous Watts.
0
1200
2400
3600
4800
% Slip
0
10
20
30
40
50
60
70
80
90
100


Power Factor



CIRCLE DIAGRAM
FOR
WESTINGHOUSE INDUCTION MOTOR
400 VOLTS 19 AMPERES PER TERMINAL
2 PHASE 1120 R.P.M.
SCALE { 1 INCH = 10 AMPERS
1 INCH = 3890 WATTS

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3 0112 082195857